# DYNAMICS OF FOREST STRUCTURE, TREE ABOVEGROUND CARBON AND DIPTEROCARPACEAE SEEDLINGS GROWTH IN SELECTIVELY LOGGED FOREST OF SABAH, MALAYSIAN BORNEO

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This dissertation is dedicated to my husband, Hamzah and my children Alan and Danish. Thank you very much for your endless understanding, patience, wisdom, love, support and encouragement. Also to my parents and brothers, thank you for your motivation and support.

# Contents

# Summary

In this thesis, I studied various sites with different types of tropical forest, and at different levels of disturbance, in Sabah, Malaysian Borneo in order to understand dipterocarp trees species diversity, growth, mortality and aboveground carbon stocks. I also study the effectiveness of enrichment planting in selectively logged forest.

In Chapter 2, I quantify total aboveground carbon stocks along an altitudinal gradient from lowland rainforest (600 m asl.), though lower montane rainforest (1000 m asl.) and to upper montane rainforest (1800 m asl.) in unlogged and selectively logged forest areas. I also determine whether the forests I included in this study acted as a carbon source or a carbon sink in at (2005 - 2006 and 2009 – 2010). My preliminary observations in this study show that tree density and diameter at breast height (dbh) size, and tree aboveground carbon stocks were different along an altitudinal gradient both in unlogged and selectively logged forest. I found that the number of tree stems in primary forest was higher in the upper montane forest and decreased in lower montane forest and lowland forest, and the size of tree stems decrease with increasing topography elevation. I found that the aboveground carbon stocks of trees decline with increasing topography elevation both in unlogged and selectively logged forest. Furthermore, in selectively logged forest, I observed that forest structure recovery in terms of tree density; basal area and tree aboveground carbon were greatest in lowland forests compared to lower montane forests. Despite this, I determined that undisturbed lower and upper montane forest had a higher carbon stock when compared to disturbed lowland forests.

In chapter 3, I examine the aboveground carbon stock in trees, its relationship to tree species diversity and tree stand basal area in selectively logged lowland dipterocarp forest (0 – 300 m asl.) and selectively logged hill dipterocarp forest (300 – 600 m asl.), which in both cases had been logged 14 years previously, at the edge of Imbak Canyon Conservation Area in Central Sabah. Nine permanent plots of 20 m x 50 m (0.1 ha each) were established along 3 km transects crossing the selectively logged lowland and selectively logged hill dipterocarp forests. A total of 871 trees belonging to 39 plant families and 133 species were sampled. Tree species diversity, tree density, tree stand basal area and tree aboveground carbon were found to vary between selectively logged lowland and selectively logged hill dipterocarp forest. Dipterocarpaceae, Euphorbiaceae, Myrtaceae and Lauraceae were the most common families recorded in both forest vegetation types. *Macaranga depressa*, *Eugenia* spp*.,* *Aglaia korthalsii, Litsea* spp*., Palaquium* spp. *and Shorea macrophylla* had higher importance value index (IVI) in hill dipterocarp forest whereas *Eugenia* spp., *Macaranga depressa, Mallotus* spp., *Shorea macroptera, Litsea* spp. and *Macaranga hypoleuca* had higher IVI in selectively logged lowland dipterocarp forest and could therefore be considered the dominant species. The Shannon diversity index for both forest vegetation types was higher in trees of dbh class of 5 – 10 cm, followed by the 11 – 20 cm and 21 – 40 cm dbh classes. Dbh class of > 80 cm was not present in the selectively logged hill dipterocarp forest. Tree densities were highest in hill dipterocarp forest (1,085 trees $ha^{-1}$) in contrast to selectively logged lowland dipterocarp forest (874 trees $ha^{-1}$). Selectively logged Lowland dipterocarp forest however had a higher tree stand basal area of 31.23 $m^2$ $ha^{-1}$ and tree aboveground carbon of 110.83 Mg C $ha^{-1}$, in contrast to selectively logged hill dipterocarp forest with a lower tree stand basal area of 15.95 $m^2$ $ha^{-1}$ and tree aboveground carbon of

65.14 Mg C ha$^{-1}$. These attributes indicated that a 14 years recovery period from logging in selectively logged lowland and selectively logged hill dipterocarp forests produced varied forest structure dynamics and may require different forest management strategies.

In Chapter 4, I assessed 21 year-old dipterocarp species which had been enrichment planted in areas logged using with two different methods, namely high lead and tractor logging. The study dipterocarp species were *Dryobalanops lanceolata, Parashorea* spp.*, Shorea leprosula and Shorea ovalis*. Growth, mortality and biomass stock of these species were analysed for both logging techniques. I found that growth, carbon stocks and mortality of dipterocarp species varied between the logging techniques. The different logging techniques have influenced the annual mean diameter growth and mortality of all species. Forest disturbances level caused by different logging techniques affected the growth of trees, which differed with species. I found that the selection of species is important for the recovery of selectively logged forest. As a commercial timber, Dipterocarpaceae species usually felled during logging which some cases the species will be total remove and disappear. Dipterocarpaceae species is very locality to specific environment and hardly recover without the seeds sources. Using indigenous species in enrichment planting could therefore facilitate the recovery of selectively logged forests, enhancing biodiversity and ecosystem functioning. This will provide the foundations for sourcing seed and production of planting material for longer term restoration in regards towards sustainable forest management practices.

In Chapter 5, I examined the performance of nine Dipterocarpaceae and one Lauraceae species planted on degraded land on the campus of Universiti Malaysia Sabah (UMS) using three different approaches of planting treatments: i) enrichment line planting with ten species in the degraded forest areas, ii) open line planting with two species in an area of open slope dominated by the non-native grass *Imperata cylindrica* and iii) dense grid planting with four species under girdled *Acacia mangium* trees. The study species selected were dipterocarps, namely *Dryobalanops lanceolata, Hopea sangal, Parashorea tomentella, Shorea argentifolia, Shorea fallax, Shorea macroptera, Shorea parvifolia, Shorea smithiana, Vatica albiramis* and the Lauraceae *Eusideroxylon zwageri.* I estimated growth and mortality rates among species planted in each planting treatments separately. The lack of a randomization blocked design and imbalances in species occurrence within the different treatments limited my study. This study suggests, by planting four year old seedlings, providing adequate nutrients and systematic maintenance, indigenous tree species grew well in full sunlight with little shading, and even in the areas dominated by the invasive grass, *I. cylindrica*.

In Chapter 6, I synthesize and discuss the main findings of each study. Firstly, the pattern of tree aboveground carbon stocks at different gradient both in unlogged and selectively logged forest. Secondly, the relationship between tree aboveground carbon stocks and tree diversity after selective logging. Thirdly, performance of dipterocarp species enrichment planted in forest selectively logged forest using different methods. Fourthly, performance of indigenous species planted using different planting methods. I also discuss the implications for forest restoration and management in enhancing the biodiversity and ecosystem functioning at degraded forests. In the section on Future

Research Recommendations, I discuss my finding regarding unlogged and selectively logged forest and the effectiveness of enrichment planting in selectively logged forest.

# Zusammenfassung

In der vorliegenden Arbeit untersuchte ich tropische Wälder an mehreren Standorten mit verschiedenen Bewirtschaftungsintensitäten in Sabah, Malaysia. Dazu gehörten auch Ergänzungspflanzungen in Waldbausystemen mit einzelstammweiser Nutzung. Mein Ziel war es, Diversität, Wachstum und Mortalität von Bäumen aus der Familie der Dipterocarpaceae (Flügelfruchtgewächse) und die Kohlenstoffspeicherung in diesen Wäldern zu verstehen.

In Kapitel 2 quantifiziere ich den gesamten oberirdischen Kohlenstoffvorrat in Bäumen (above ground carbon, AGC) entlang eines Höhengradienten von Tieflandregenwald (600 m.ü.M), tieferem (1000 m.ü.M) und höherem Bergregenwald (1800 m.ü.M) in unberührten Primärwald und selektiv bewirtschafteten Waldflächen. Ich untersuche auch, ob die Waldflächen in dieser Studie, im Zeitraum 2005 - 2006 und 2009 - 2010, insgesamt eine Kohlenstoffquelle oder -senke darstellten. Die vorläufigen Beobachtungen zeigen, dass Baumdichte, Brusthöhendurchmesser und Baumkohlenstoffvorrat in Natur- und Wirtschaftswald mit der Geländehöhe variieren. Im Primärwald war die Anzahl der Stämme im höheren Bergregenwald am höchsten, geringer im tieferen Bergregenwald und am niedrigsten im Tieflandregenwald, während die Dicke der Bäume mit abnehmender Geländehöhe zunahm. Auch der oberirdische Kohlenstoffvorrat nahm sowohl im Primärwald als auch auf den bewirtschafteten Waldflächen mit zunehmender Geländehöhe ab. Des Weiteren erholte sich die Waldstruktur in Bezug auf Baumdichte, Baumgrundfläche und oberirdischem AGC nach selektivem Einschlag im Tieflandwald schneller als im tieferem Bergwald. Auch waren Grundfläche und AGC im Tiefland höher als im tieferen Bergwald. Dennoch schliessen wir, dass Primärwald in montanen Lageneinen höheren Kohlenstoffvorrat hatten, als der Wirtschaftswald im Tiefland.

In Kapitel 3 stelle ich die Ergebnisse meiner Arbeiten am Rand des Naturschutzgebietes „Imbak Canyon" in Zentral-Sabah dar. Ich untersuchte den AGC und sein Verhältnis zur Baumartenvielfalt und Baumgrundfläche in Dipterocarpaceen-Tieflandwald (0 - 300 m ü. NN.) und Hügellandwald (300 - 650 m ü. NN.), welche beide vor 14 Jahren selektiv geerntet wurden. Neun Dauerbeobachtungsflächen (je 20 m x 50 m, 0,1 ha) wurden entlang von 3 km langen Transekten durch Wirtschaftswald im Tiefland und den Hügellagen errichtet. Insgesamt untersuchte ich 871 Bäume aus 39 Pflanzenfamilien und 133 Baumarten. Diversität, Dichte, Grundfläche und AGC unterscheiden sich zwischen Wäldern im Tief- und Hügelland. An beiden Standorten sind Dipterocarpaceae, Euphorbiaceae, Myrtaceae und Lauraceae die häufigsten Familien. *Macaranga depressa*, *Eugenia* spp., *Aglaia korthalsii*, *Litsea* spp., *Palaquium* spp. und *Shorea macrophylla* sind die dominanten Baumarten im Hügelwald, was durch einen hohen „Importance value index" (IVI) ausgedrückt wird. Im Tieflandwald sind dagegen *Eugenia* spp., *Macaranga depressa, Mallotus* spp., *Shorea macroptera, Litsea* spp. und *Macaranga hypoleuca* die häufigsten Arten. An beiden Standorten ist der Shannon- Diversitätsindex am höchsten für Bäume mit einem Brusthöhendurchmesser (BHD) von nur 5 – 10 cm und fällt dann in den weitern Klassen bis 40 cm ab. Bäume mit einem BHD über 80 cm kommen im selektiv genutzten Dipterocarpaceen-Hügellandwald nicht vor. Mit 1085 Bäumen pro Hektar ist die Baumdichte im Hügellandwald größer als im Tieflandwald (874 $ha^{-1}$). Tieflandwälder haben hingegen mit 31,23 $m^2$ $ha^{-1}$ eine größere Baumgrundfläche und mit 110,83 Mg C $ha^{-1}$ auch einen grösseren Kohlenstoffvorrat, während die

Grundfläche im Hügellandwald nur 15,95 $m^2$ $ha^{-1}$ beträgt und der Kohlenstoffvorrat 65,14 Mg C $ha^{-1}$. Diese Ergebnisse zeigen, Dipterocarpaceen-Wald, der vor 14 Jahren selektiv genutzt wurde je nach Höhenlage eine unterschiedliche strukturelle Dynamik aufweist und daher auch verschiedene Waldmanagementstrategien erfordern kann.

Kapitel 4 beschreibt die Untersuchungen zu 21 Jahre alten Ergänzungspflanzungen von Dipterocarpaceen-Arten auf Flächen mit unterschiedlichen Holzbringungsverfahren: Seilkran und Rückeschlepper. Wachstum, Mortalität und Kohlenstoffvorrat der Dipterocarpaceen-Arten *Dryobalanops lanceolata, Parashorea* spp.*, Shorea leprosula* und *Shorea ovalis*variierten zwischen den beiden Bringungstechniken, welche den jährlichen mittleren Durchmesserzuwachs und die Mortalität aller untersuchten Arten beeinflusste. Diese Studie belegt, dass die Auswahl der Baumarten sehr wichtig ist, um die Erholung von degradiertem Wald zu unterstützen. Das Ausmaß der Störung des Baumwachstums durch die verschiedenen Bringungstechniken hängt von den Baumarten ab. Die meisten Dipterocarpaceen-Arten werden zur kommerziellen Holznutzung gefällt, wobei es vorkommen kann, dass einzelne Arten komplett entfernt werden und damit aus dem Gebiet verschwinden. Da diese Dipterocarpaceen sehr lokal unter speziellen Umweltbedingungen wachsen, erholen sich die Bestände kaum ohne Samenquellen. Deshalb kann die Ergänzungspflanzung mit Keimlingen einheimischer Baumarten die Erholung des selektiv abgeholzten Waldes erleichtern und damit zu mehr Biodiversität und verbesserter Funktion des Ökosystems führen. Damit wird der Grundstein eine für erneute Samenproduktion für die langfristig Restaurierung mit dem Ziel der nachhaltigen Waldbewirtschaftung gelegt.

Im 5. Kapitel erläutere ich die Leistung von neun Dipterocarpaceen- und einer Lauraceae-Baumart, die auf degradiertem Gelände des Campus der Universität Malaysia Sabah (UMS) gepflanzt wurden. Dabei vergleiche ich den Erfolg von drei verschiedenen Pflanzmethoden: i) Ergänzungspflanzung von zehn Arten in Reihen in den degradierten Waldflächen, ii) Anpflanzung von zwei Arten in offenen Reihen an einem baumlosen Hang der von der invasiven Grasart *Imperata cylindrical* dominiert wird und iii) Anpflanzung von vier Arten in einem dichten Verband unter geringelten *Acacia mangium* Bäumen. Die ausgewählten Baumarten sind die Dipterocarpaceen-Arten *Dryobalanops lanceolata, Hopea sangal, Parashorea tomentella, Shorea argentifolia, Shorea fallax, Shorea macroptera, Shorea parvifolia, Shorea smithiana, Vatica albiramis* und die Lauraceae-Art *Eusideroxylon zwageri.* Unterschiede im Wachstum und in der Mortalität zwischen den Arten wurden für die drei verschiedenen Pflanzmethoden getrennt gemessen. Der Vergleich des Anpflanzungserfolgs wird durch die fehlende Balance zwischen den Arten und durch die nicht zufällige Verteilung der Blöcke begrenzt. Meine Ergebnisse zeigen, im Gegensatz zur üblichen Meinung, dass vier Jahre alte Keimlinge einheimischer Baumarten, die im Boden mit ausreichend Nährstoffen versorgt und systematisch gepflegt werden, gut in vollem Sonnenlicht wachsen, und das sogar auf Flächen, die von dem invasiven Gras *Imperata cylindrica* dominiert sind.

In Kapitel 6 greife ich die wichtigsten Ergebnisse aller Studien auf und diskutiere die Zusammenhänge. Dabei behandeln wir erstens die Muster des AGC in natürlichen und in Wirtschaftswäldern verschiedener Höhenlagen. Zweitens analysiere ich das Verhältnis zwischen dem Kohlenstoffvorrat und der Baumartenvielfalt nach selektiver Holznutzung. Drittens untersuche ich das Wachstum von verschiedenen

Dipterocarpaceen-Arten nach Ergänzungspflanzung auf mit verschiedenen Holzbringungstechniken bewirtschafteten Waldflächen und viertens den Erfolg von verschiedenen Anpflanzungsstrategien bei einheimischen Baumarten. Ich erläutere zudem die Konsequenzen unserer Ergebnisse für die Renaturierung und das Management von tropischen Wäldern, welches die Biodiversität und Ökosystemfunktionen fördert. Im Rahmen von Empfehlungen für weitere Forschung diskutiere ich meine Ergebnisse zu den Unterschieden zwischen natürlichen, nicht zur Holzgewinnung genutzten, und selektiv eingeschlagenen Wäldern und die Wirksamkeit von Ergänzungspflanzungen im Wirtschaftswald.

# Chapter 1

## General Introduction

**Tropical forest dynamics**

The world´s tropical forests cover an area of approximately 750 million ha and are predominately located in three regions; South America (53%), Africa and South East Asia (FAO, 2005). Tropical forests support high levels of biodiversity and are the most diverse terrestrial habitats, harbouring more than 50% of the world species (Whitmore *et al.*, 1990). Tropical rain forests are also about one and a half times more productive than temperate forests and mangrove swamp forests (Smith, 1980).

The importance of tropical forests in respect to global ecosystem, biodiversity and carbon cycles has been widely discussed (Brooks *et al.*, 2002; Malhi, 2010; Malhi and Grace, 2000; Malhi and J. Wright, 2004; Sodhi *et al.*, 2004; Whitmore *et al.*, 1990). Most authors have highlighted that tropical forest ecosystems have the capacity to store and process large amounts of carbon. However, tropical forests are threatened by degradation (due to logging) and land-use change (driven by agricultural expansion). Degraded forests, in particular, are often subject to conversion to other land uses, including agricultural and urban development in order to fulfil demands of the expanding population (Koh *et al.*, 2013; Rudel *et al.*, 2009). Population pressure is one of the major factors driving the worldwide forest and biodiversity loss (Brooks *et al.*, 2002; Hanski, 2011), which has resulted in a 50% decrease of the total area of these unique ecosystems (S. J. Wright, 2005).

Despite the rapid change of forest habitat in tropical regions, many studies have been conducted in degraded forest in order to better understand forest ecosystem structure and functioning, which in turn could assist in understanding biodiversity conservation (Edwards *et al.,* 2011; Sodhi *et al*., 2010). Certainly, conserving primary and old growth forests is important for biodiversity conservation strategies, but restoring and maintaining connectivity may also enhance the conservation value of degraded forests (Sodhi *et al*., 2010).

**Tropical forests in Southeast Asia**

Tropical forests in Southeast Asia make up about 15% of the world´s tropical forests (FAO, 1995) and are among the most bio-diverse terrestrial ecosystems with, for example, 200 or more plant species per hectare (Gillison *et al.,* 2002). In Malaysia, tropical forests occupy about 30.6 million ha (FAO, 2006). The Malaysian forests have been described as climax forests and are among the oldest forests and the most diverse globally in terms of species richness (Ashton, 1969; Richards, 1952; Whitmore and Burnham, 1984).

Borneo is the third largest island in the world and is a hotspot for biodiversity. The richness of biodiversity is the most important characteristic of the tropical rainforest of Borneo. According to Burslem *et al.*(2001), there are more tree species found in 0.5 square kilometers of tropical forest than found in all the forests of Europe or North America. In Borneo the family Dipterocarpaceae also shows high endemism, with 155 out of 267 species being endemic to this massive island (Ashton, 1982), and 183 (69%) of these species are found in Sabah, its Northern part (Ashton, 2004). The variety of species in tropical forests has stimulated interest amongst ecologists to understand the mechanisms that maintain such diversity.

Degradation through logging activities and deforestation for agricultural development has rapidly depleted forest habitat areas across the region. Forest cover in Southeast Asia has been estimated to have declined by approximately 1% of the total area per year from 2000 to 2010, mainly as a result of plantation development (Miettinen et al., 2011). Lowland forest areas were the most converted habitats with annual losses of about 1.2%.

Koh and Wilcove (2008) reported that conversion of degraded forest to oil palm plantations increased by 55% between 1990 and 2005. It has become a main factor driving the loss of lowland forest and biodiversity in Southeast Asia (Fitzherbert *et al.*, 2008; Sayer *et al.*, 2012). Awareness of the importance of forest ecosystems, including degraded forests, has increased and has led to a better understanding by agricultural developers and other agencies in Southeast Asian nations on the importance of avoiding conversions of forests to oil palm areas (Koh and Wilcove, 2008; Lee *et al*., 2013; Sayer *et al.*, 2012).

Recently, many studies have investigated forest restoration through enrichment planting in Southeast Asia. The involvement of many local government agencies and international non-government organizations (NGOs) in embarking on sustainable forest management and forest restoration projects has helped expand awareness and understanding of protecting forest habitats. For example, Yayasan Sabah, the biggest forest concessionaire in Sabah, Malaysia, collaborated with several NGOs, such as the FACE Foundation of the Netherland and a Swedish furniture company IKEA to rehabilitate, respectively, approximately 25,000 ha of selectively logged lowland dipterocarp forest in the Ulu Segama Forest Reserve, Lahad Datu and 18,500 ha of selectively logged lowland dipterocarp in the Kalabakan Forest Reserve, Kalabakan (Reynolds *et al.,* 2011; Romell *et al*., 2008).

**Forest Land Use in Sabah**

Over the past decades, the landscape of Sabah has changed significantly. LANDSAT images of forest cover changes from 1973 to 2010 in Borneo (Gaveau *et al.*, 2014) indicated that Sabah has recorded forest cover losses of 39.5% and 30.7% in Kalimantan. Other studies (Marsh and Greer, 1992) reported that forests areas at the end of 1980 made up about 60% of the land area with most of these areas Permanent Forest Reserves (33,385 km2) and State Parks (2,450 km2). In 2010 forest areas in Sabah had declined by 7,054 $km^2$ with the total area of natural forest reduced to 37,600 $km^2$ (Reynolds *et al*., 2011). The changes in the forest habitat in Sabah was mainly a result of selective logging activities and agricultural development (McMorrow and Talip, 2001; Reynolds *et al.*, 2011). It was also reported that due to the extreme dry periods of El Nino in 1982 – 1983, Sabah experienced extensive forest loss as a result of fire (Woods, 1989).

According to the Malaysian National Forest Policy, about 45% of Sabah's land area was designated to become permanent forest reserve but Sabah is also one of the Malaysian states known to have one the largest areas planted with oil palm, covering about 17% of the total land area (Morel *et al.,* 2011). An extension of restoration and timber plantation in degraded forests and redundant land and the conversion of more forest reserves into protected areas, have increased awareness to support sustainable forest management and enhanced biodiversity conservation at local scales (Anon, 2013). The Sabah Forestry Department reports that totally protected forests in Sabah cover 1,553,262 ha or about 21% of total land area (WWF, 2014), i.e. the highest amount of protected forest cover among the states of Malaysia (Daily Express, 2014 November 14).

**Forest rehabilitation in Sabah**

Forest rehabilitation is a management process to reverse the reduction of tree cover in degraded forests (Mori, 1980). According to Appanah & Turnbull (1998) and Lamb (1998), there are three rehabilitation strategies employed to restore degraded forests; reclamation, rehabilitation and ecological restoration. In Sabah, forest rehabilitation has been achieved either through enrichment planting or silvicultural treatment, dependent on the severity of forest degradation.

Tropical forests are subject to disturbance at the small scale (usually natural disturbances) and at large scales (often caused by human activities such as logging or wide-spread fire) (Lamb, 1994). Uncontrolled logging using heavy machinery with poor extraction methods and shifting cultivation are two of the major drivers of forest disturbance (Sabogal, 2005). In Sabah, industrial logging has resulted in the reduction of the natural regenerative capacity of forests, and has especially impacted the Dipterocarpaceae (Slik *et al*., 2003) (Garcia and Falck, 2003). In response to this, various countries have attempted to rehabilitate deforested lands although the current rates of degradation and deforestation still outpace rehabilitation (Lamb, 1994). If the forests' ecosystem functions and services, as well as commercial revenue from sustainable timber extraction are to be maintained then forest restoration will have to be essential (Kobayashi *et al.,* 2001).

In order to rehabilitate the selectively logged forest, enrichment planting is often required. Lugo (1988) reviewed and addressed some of the issues in the rehabilitation of the degraded forest ecosystems in the humid tropics and concluded that the key strategy for tropical forest rehabilitation is to use natural processes. Appanah and Weinland (1993) proposed enrichment planting using indigenous species on degraded forests to accelerate recovery based on species site matching especially to address the soil compaction effect. These were supported in the review study by Kettle (2009), on the constraints of restoration of lowland dipterocarp forests in Southeast Asia, where he also advocates using dipterocarps for restoration.

**Conclusion**

In this thesis I study: 1) the dynamics of tropical forest structure in both unlogged and selectively logged areas along an altitudinal gradient; 2) the effectiveness of dipterocarp enrichment planting schemes in restoring selectively logged forests in response to different logging techniques; and, 3) the growth and survival of Diptercarpaceae and Lauraceae seedlings planted under different conditions of degraded land. First, I quantified the tree diversity and tree aboveground carbon stocks along an altitudinal gradient range from 600 to 1800 m asl., both in the unlogged and selectively logged forest in Crocker Range Park (Chapter 2). Second, I examined tree aboveground carbon stocks and its relationship with tree diversity and basal area in the 14 year-old logged-over lowland dipterocarp forest and hill dipterocarp forest at the edge of Imbak Canyon Conservation area (Chapter 3). Third, I assessed 21 year-old planted dipterocarp species in selectively logged forest areas following two different logging techniques, namely high lead and tractor logging (Chapter 4). Finally, I examined the performance of nine species of Dipterocarpaceae and one species of Lauraceae in degraded forests on the Universiti Malaysia Sabah campus (Chapter 5). Chapter 6 provides a general discussion of these studies.

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# Chapter 2

## Forest Structure and Aboveground Carbon Stocks Along an Altitudinal Gradient in Crocker Range Park, Sabah, Malaysia.

**Abstract**

Numerous studies have established carbon density maps for different forest areas of Borneo. However, little is known about the changes along altitudinal gradients. The Crocker Range Park in Sabah offers an ideal setting to address this. My study objectives are 1) to quantify total aboveground carbon storage along an altitudinal gradient, ranging from lowland rainforest (up to 750 m asl.) and lower montane rainforest (750 - 1500 m asl.) to upper montane rainforest (1500 - 2100 m asl.); 2) to quantify the carbon storage in unlogged and selectively-logged forest areas, and 3) to determine if the forest areas being studied acted as a carbon source or a carbon sink between the two survey rounds in the years 2005 - 2006 and 2009 - 2010. I used the data set collected from the permanent plots of the forest ecology monitoring project; a collaborative effort between Sabah Parks and the Institute for Tropical Biology and Conservation (ITBC) at Universiti Malaysia Sabah (UMS) together with the School of International Forestry of UMS, Sabah Forestry Department and Yayasan Sabah. Six sites were selected based on altitudinal variation (from lowland forest to montane forest and unlogged forest) and unlogged versus selectively logged forest. The sampling was carried out at Inobong, Keningau, Mahua, Mount Alab, Ulu Senagang and Ulu Kimanis. Crocker Range Park (CRP) is covered by three types of unlogged forest, namely lowland forest, lower montane forest and upper montane forest, and two forest habitats in selectively logged areas, namely lowland forest and lower montane forest. The size of plots was 50 x 50 m (0.25 ha). A census of trees of diameter at breast height (dbh) of ≥ 5 cm and heights of above 1.3 m was carried out. The sampling design is unbalanced with no upper montane selectively logged forest as the vegetation does not include commercial timber species and there has been no logging activity. My preliminary observation shows that tree density and carbon storage declined with altitude. Vegetation density at the first census showed that lowland forest was

dominated by Euphorbiaceae (449 trees $ha^{-1}$), Dipterocarpaceae (158 trees $ha^{-1}$) and Myrtaceae (106 trees $ha^{-1}$). Lower montane forest had a higher density of stems including Annonaceae (270 trees $ha^{-1}$), Meliaceae (266 trees $ha^{-1}$) and Lauraceae (80 trees $ha^{-1}$). In upper montane forest, the families with the highest densities were Myrtaceae (1168 trees $ha^{-1}$), Podocarpaceae (764 trees $ha^{-1}$), and Theaceae (588 trees $ha^{-1}$). The total aboveground carbon (AGC) during the first and second census were as follows: lowland forest (121 Mg C $ha^{-1}$; 183 Mg C $ha^{-1}$), which had higher carbon stocks in comparison with lower montane forest (84 Mg C $ha^{-1}$; 80 Mg C $ha^{-1}$) and upper montane forest (45 Mg C $ha^{-1}$; 45 Mg C $ha^{-1}$).

**Introduction**

Tropical forests are known as one of the most diverse habitats on earth (Connell, 1978; Hill and Hill, 2001) and contain some of the largest aboveground carbon stocks (Clark *et al*., 2011; Dixon *et al*., 1994; Gibbs *et al*., 2007). A study by Saatchi *et al.* (2011) using inventory plots and satellite light detection and ranging (LiDAR) estimated that the tropical forest carbon stocks stored in the forests of Latin America, Southeast Asia and sub-Sahara Africa and accounted for 49%, 26% and 25% of the global total respectively. In Southeast Asia many studies have been carried out which estimate the aboveground carbon stocks in old growth forest and logged forest (Baccini *et al*., 2012; Laumonier *et al*., 2010; Loki *et al*., 2014; Ngo *et al.*, 2013; Saner *et al*., 2012). However, there is significant uncertainty over the size of aboveground carbon stocks.

Studies have identified that carbon in tropical forest ecosystems is primarily stored in biomass and soil organic matter (Dixon *et al.,* 1994; Ngo *et al*., 2013; Saner *et al*., 2012). Carbon stocks in aboveground biomass may be more vulnerable to loss than in-soil (or soil-bound) carbon, with the aboveground carbon loss as a result of both natural disturbance and land-use change (Cramer *et al*., 2004). Rapid increases in deforestation rates have motivated interest in adopting approaches which aim to incentivize the retention of forest-based carbon schemes such as Reducing Emissions from Deforestation and forest Degradation (REDD) (Imai *et al.*, 2014; Kettle, 2012; Putz and Romero, 2012). A basic step in the REDD initiative was to gather comprehensive data on carbon stocks, which required quantifying aboveground biomass and models to estimate the carbon stocks in different region and forest types (Basuki *et al.*, 2009; Brown, 1997; Chave *et al*., 2005). Indeed, accurate methods for forest measurement, using allometric and a combination of ground-based data with remote sensing to estimate national carbon stocks were widely investigated (Gibbs *et al.*, 2007). The selection of an appropriate models is important in order to reduce uncertainties in estimating forest biomass and carbon stocks (Rutishauser *et al*., 2013).

The dynamics of aboveground carbon stocks of different forest types is directly determined by the forest structure and biomass distribution, respectively. These are influenced by the local and regional landscape, which is directly correlated with the history of the areas and forest structure (Brown, 1997). Previous studies have also observed that forest structure, biomass and tree aboveground carbon stocks were differentiated according to logging disturbance intensity (Pinard and Putz, 1996; Tangki and Chappell, 2008), species composition (Baker *et al.*, 2004), soil condition (Lal, 2005), climate (Malhi *et al.*, 2006; Stegen *et al*., 2011), successional stage (Fonseca *et al*., 2011), and topography (D. B. Clark and D. A. Clark, 2000; Laumonier *et al*., 2010).

Although many studies have been conducted to measure the capability of forests for carbon sequestration in Southeast Asia (Adachi *et al.*, 2011; Laumonier *et al.*, 2010; Ngo *et al.*, 2013) and within Borneo (Imai *et al*., 2009; Saner *et al.,* 2012), its variation and distribution in relation to different environmental conditions and forest structure are still poorly documented, especially along altitudinal gradients. Therefore, Crocker Range Parks in Sabah offers an ideal environment to better understand aboveground carbon stocks along this gradient. Crocker Range Parks is covered by both unlogged and selectively logged forest which consist of three forest habitats ranging from lowland rainforest (up to 750 m asl.) and lower montane rainforest (750 - 1500 m asl.) to upper montane rainforest (1500 - 2100 m asl.) In this study**,** I (1) quantified how the forest structure and tree aboveground carbon stocks are distributed along an altitudinal gradient; and (2) evaluated the change of tree aboveground carbon stocks along the altitudinal gradient after 4 years.

## Methodology

### Study area

The study area is situated within the Crocker Range Park (Figure 1). Study plots were established for long term monitoring. This project is a collaborative effort between Sabah Parks and the Institute for Tropical Biology and Conservation (ITBC) at Universiti Malaysia Sabah (UMS) together with the School of International Forestry of UMS, Sabah Forestry Department and Yayasan Sabah (Repin *et al.*, 2012). Six sites were selected based on altitudinal variation from lowland forest to montane forest and unlogged forest versus selectively logged forest. The sampling was carried out at Inobong, Keningau, Mahua, Mount Alab, Ulu Senagang and Ulu Kimanis. Crocker Range Park (CRP) is covered by three types of forest habitat in unlogged forest, namely lowland forest, lower montane forest and upper montane forest, and two forest habitats in selectively logged areas, namely lowland forest and lower montane forest (Figure 1).

### Plot design and data collection

Sampling plots were established in 2005. Six sites were selected based on altitudinal variation from lowland forest to montane forest and unlogged forest versus selectively logged forest (Table 1). The sampling plots are unbalanced for upper montane between unlogged forest and selectively logged forest. There is no plot established in upper montane forest for selectively logged forest as no logging activity has been conducted. In fact, the vegetation occurring in this site are not timber or commercial species. The size of plots was 50 x 50 m (0.25 ha). A census was carried out for trees with a diameter at breast height (130 cm dbh) of 5 cm and above. The first inventory was undertaken during the plot establishment in 2005 and the second inventory was carried out in year 2009.

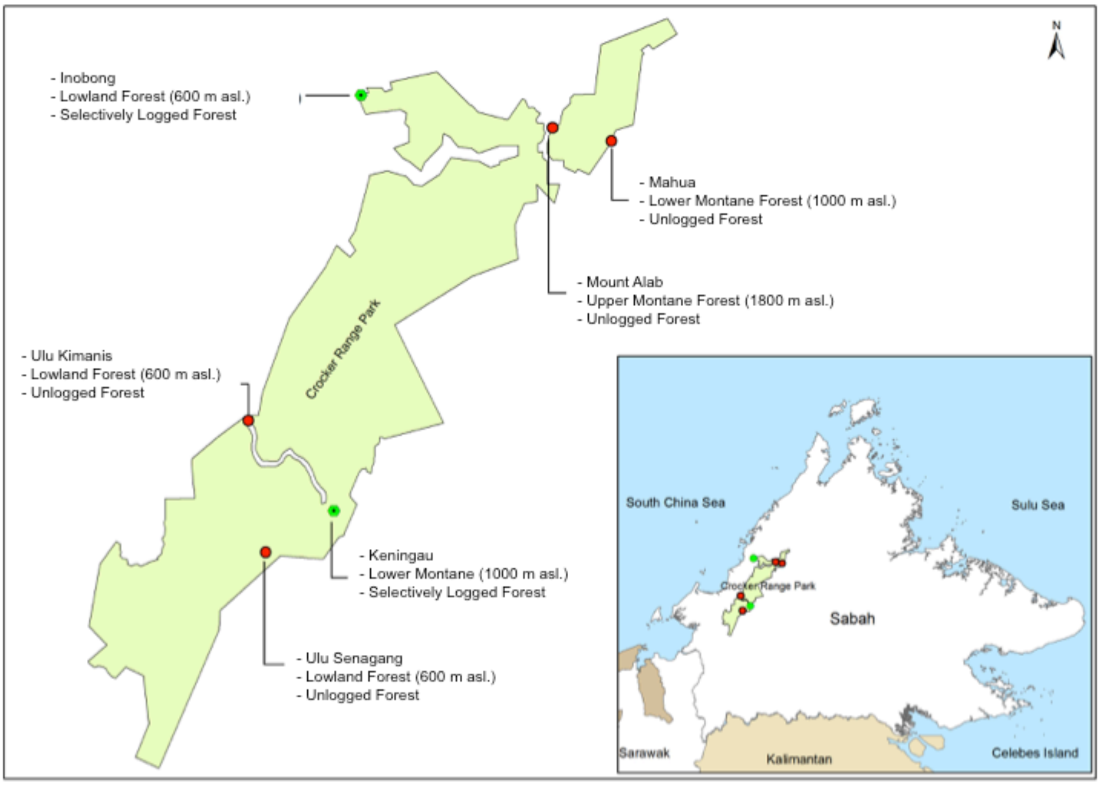


Figure 1: Location of study area and sampling plots.

Table 1. Establishment of CRP plot (Suleiman *et al.*, 2007).

| **Forest vegetation zone** | **Height (m)** | **Unlogged Forest** | | **Selectively logged** | |
|---|---|---|---|---|---|
| | | West | East | West | East |
| Upper montane | 1,500 – 2,100 | Mount Alab | – | – | – |
| Lower montane | 750 – 1,500 | – | Mahua | – | Keningau |
| Lowland | 0 – 750 | Ulu Kimanis | Ulu Senagang | Inobong | – |

**Data Analysis**

I checked and cleaned the data for two weeks assisted by a botanist of Sabah Parks. I also conducted ground truthing for all plots in 2012 for some species verification. General linear models (GLM) with a Gamma distribution and log link function was used to analyse the basal area and carbon in each dbh class size with different altitudinal zones in unlogged and selectively logged forests separately. Mean basal area and tree aboveground carbon stocks estimates are presented with lower and upper bounds of 95% confidence intervals (CI) taken from the GLM analysis. The species diversity, important value index (IVI), species diversity were calculated using the standard formula as below:

***Species diversity***

Species diversity was evaluated by using Shannon's diversity index to compare between unlogged forest and selectively logged forest.

***Shannon–Wiener Index:***

The formula is:

$$H' = -\sum_{I=1}^{s} (P_i)(\ln P_i)$$

Where $H'$ = Index of species diversity, S = Species number in the sample, $P_i$ =Proportional abundance of the *i*th species = (ni /N).

***Important Value Index (IVI)***

The important value index (IVI) was performed to investigate the overall importance role of each species in the community structure using the percentage of relative dominance (based on basal area), relative density (based on number of individual) and the relative frequency (based on frequency of occurrence of species) as follows:

- Relative dominance = (total basal area for a species / total basal area for all species) x 100
- Relative density = (number of individual of a species / total number of individual) x 100
- Relative frequency = (frequency of a species / sum frequencies of all species) x 100
- IVI = relative dominance + relative dominance + relative frequency

***Aboveground biomass and Carbon Sequestration***

To assess carbon stocks on each site, I used tree dbh and wood density to predict aboveground carbon stocks. I used the allometric equations:

$\ln(TAGB)=c+\alpha\ln(dbh)+\beta\ln(WD)$

of mixed species group derived from Basuki *et al.*(2009) where TAGB is the Total Aboveground Biomass in kg tree$^{-1}$. The values for c (intercept), α and β (slope coefficients) of the regression differ due to species grouping. WD is wood density in g cm$^{-3}$. Wood density values were referred to agroforestry database (http://db.worldagroforestry.org/wd). When not available, the wood density values were taken from the most closely related species. Tree aboveground carbon was estimated as 50% of tree aboveground biomass (Nepstad *et al.*, 1994).

## Results

### *Forest structure*

Tree density differed between forest types (Figure 2). At the first measurement of unlogged forest in year 2005, the upper montane forest had a tree density of 2,164 trees $ha^{-1}$ (95% CI: 2,156 – 2,171) significantly higher than lower montane forest of 1,024 trees $ha^{-1}$ (95% CI: 1,016 – 1,032) and lowland forest of 1,254 trees $ha^{-1}$ (95% CI: 1,250 – 1,258). At the second measurement in year 2009, tree density in the upper montane forest remained essentially unchanged at 2,164 trees $ha^{-1}$ (95% CI: 2,156 – 2,171) and in the lowland forest from 1,254 trees $ha^{-1}$; 1,252 tree $ha^{-1}$ (95% CI: 1,248 – 1,256) and in lower montane forest from 1024 trees $ha^{-1}$ to 1,008 trees $ha^{-1}$ (95% CI: 1,000– 1,016). There was effectively no change in tree density across forest types between measurements in year 2005 and 2009 in unlogged forest.

In selectively logged areas, lowland forest had a higher tree density compared to lower montane forest. The second measurement in year 2009 indicated an increase of tree density both in lowland forest from1304 trees $ha^{-1}$ (95% CI: 1,296 – 1,312) to 1,496 trees $ha^{-1}$(95% CI: 1,488 – 1,504) and lower montane forest from 760 trees $ha^{-1}$ (95% CI: 752 – 768) to 832 trees $ha^{-1}$ (95% CI: 824 – 840).

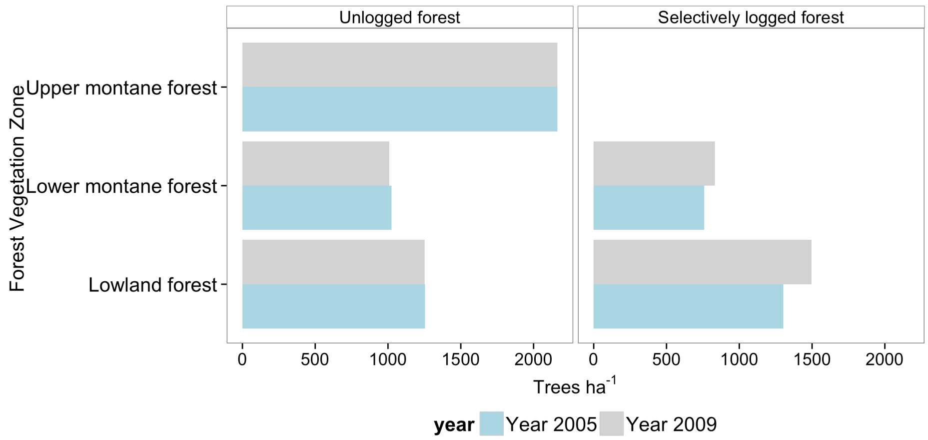


**Figure 2.** Tree density along the altitudinal zone in both unlogged and selectively logged forest in Crocker Range Park.

The distribution of tree density by dbh class in unlogged forest indicated that upper montane forest only contained a few trees above 41 cm dbh and trees above 61 cm dbh were absent (Figure 3). The selectively logged forest data indicated that trees of dbh above 41 cm have decreased in both lowland forest and lower montane forest. Both unlogged and selectively logged forest show that the highest number of trees occurs in the lowest dbh classes. Trees of dbh above 61 cm only occurred in lowland forest, both in unlogged and selectively logged forest (Figure 3).

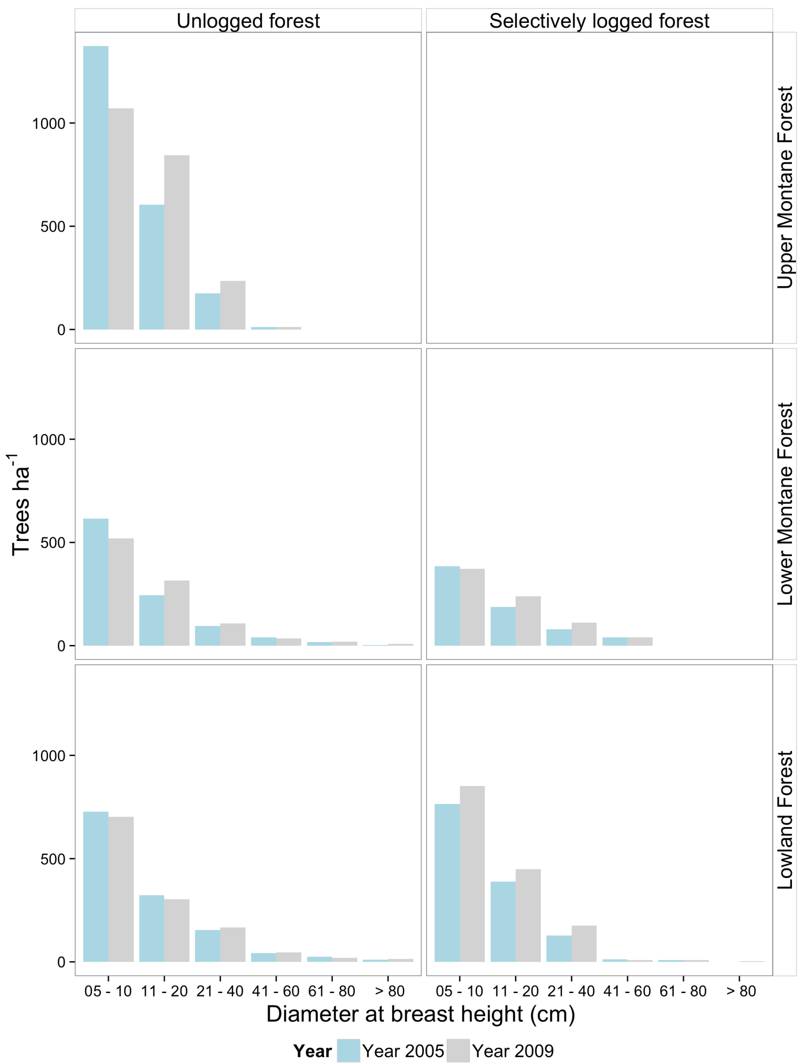


**Figure 3.** Distribution of tree density by dbh classes in lowland forest, lower montane forest and montane forest in both unlogged and selectively logged forest in Crocker Range Park.

Tree basal area varied across forest types (Figure 4). In unlogged forest, lowland forest had a higher tree basal area compared to the lower and upper montane forest. There was a significant increase in basal area in both unlogged and selectively logged forest between the measurements in 2005 and 2009 (Figure 4). Trees in dbh class 21 – 40 cm made the greatest contribution to basal area in lowland forest and upper montane forest. In selectively logged forest, lower montane forest had higher tree basal area compared to lowland forest (Figure 4). Trees in dbh classes 21 – 40 cm and 41 – 60 cm show higher tree basal area in the lowland forest and lower montane forest, respectively (Figure 5).

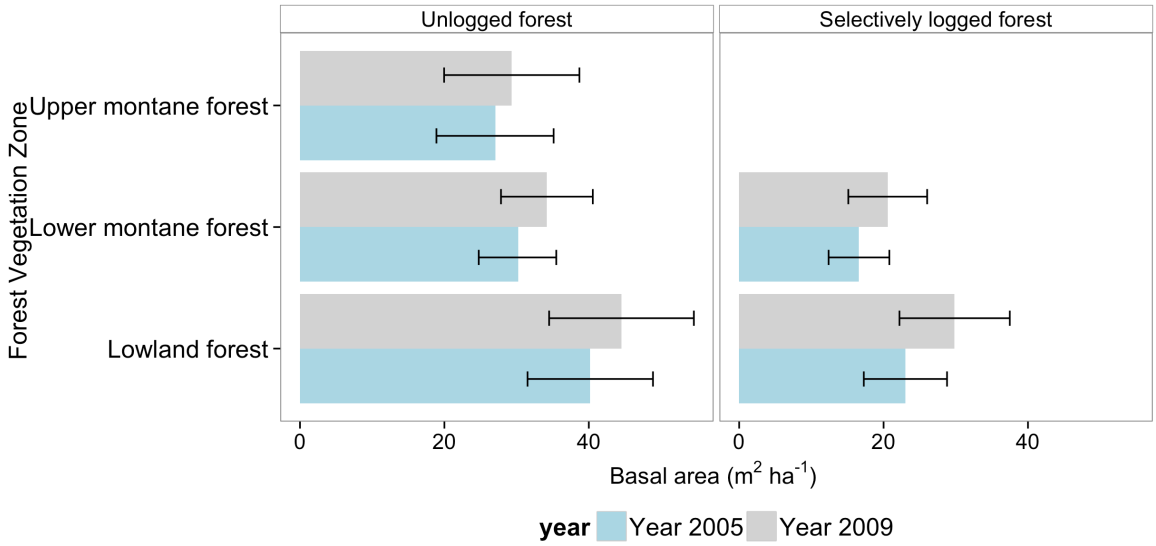


Figure 4. Tree basal area in unlogged and selectively logged lowland forest, lower montane forest and montane forest in the Crocker Range Park.

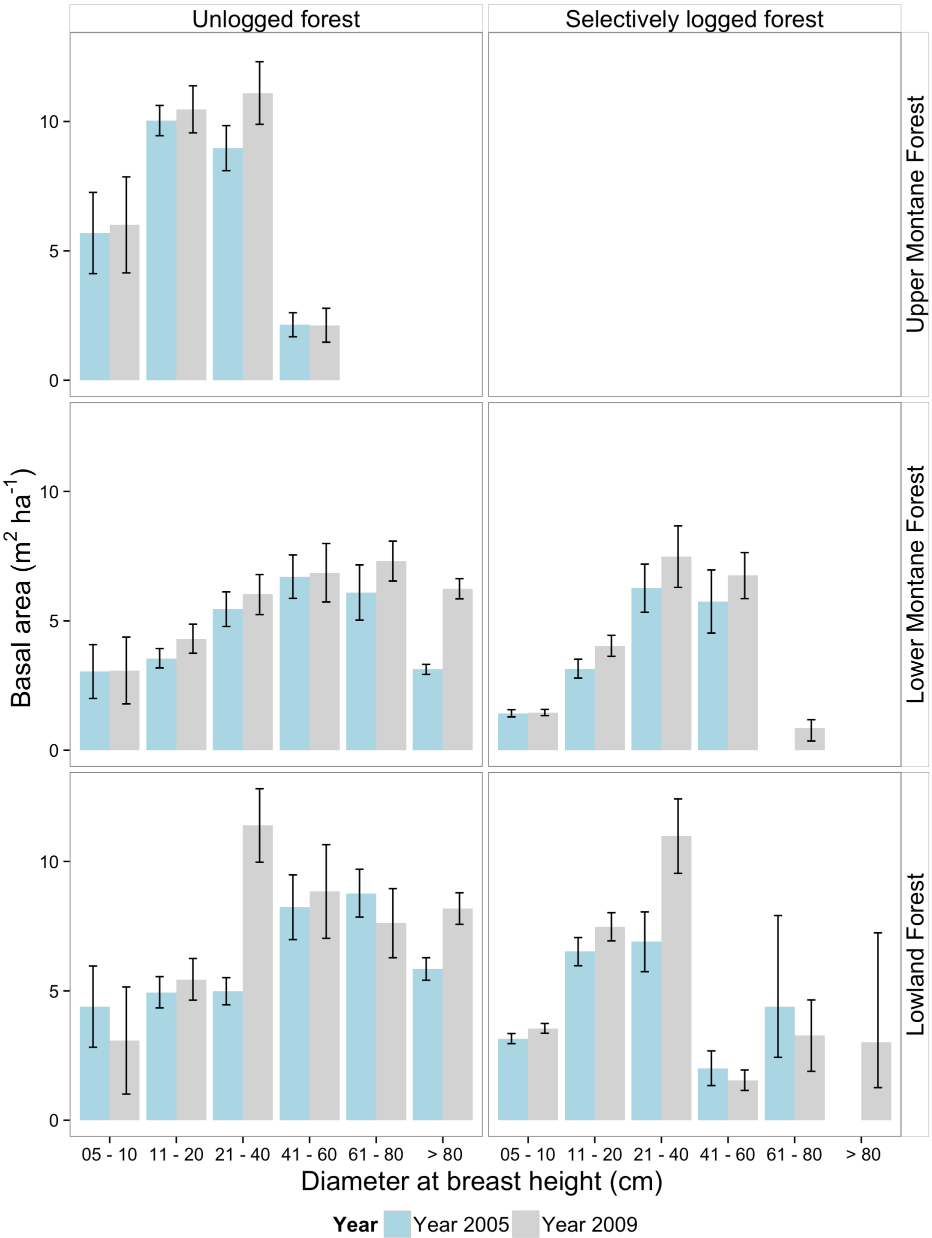


**Figure 5:** Distribution of tree basal area by dbh in unlogged and selectively logged lowland forest, lower montane forest and montane forest in the Crocker Range Park for 2005 and 2009 with 95% confidence interval from the glm models.

***Species diversity***

In unlogged forest, the Shannon index indicated that lowland forest contained a higher tree species diversity than upper montane or lower montane forest – in that order (Table 1). The second measurement in year 2009 showed that the number of families, genera and species across forest types had changed. The number of tree family, genera and species in the lower montane forest decreased, but species were added in upper montane forest. In the lowland forest the number of families and genera remained the same but there was an increase in the number of species from 265 to 270 species – small enough to be also effectively unchanged (Table 1).

Tree diversity in selectively logged lower montane forest was higher than in the lowland forest. Both selectively logged forest types had increased tree diversity (Table 2) acompared to unlogged forest (Table 1). The second measurement in 2009 indicated a reduction in the number of families in lower montane forest, but an increase in the number of genera and species. Selectively logged lowland forest had the same number of families (39) but the number of genera increased from 66 to 77 and species from 101 to 115.

In term of tree composition, there were no significant differences between survey dates in both unlogged and selectively logged forest. Common families in unlogged lowland forest the Euphorbiaceae (2005: 14.5%; 2009: 4.7%) (Table 3a) and in the unlogged lower montane forest the Annonaceae (2005: 33.6%; 2009: 34.1%) (Table 3b) and in the unlogged upper montane forest the Myrtaceae (2005; 24.6%; 2009: 23.7%) (Table 3c). Table 4a and table 4b show that Euphorbiaceae was relatively abundant in both lowland forest (2005: 43.9%; 2009: 43.1%), and lower montane forest (2005: 12.7%; 2009: 11.5%) in selectively logged forest.

Species evenness values in both unlogged and selectively logged forest varied between forest types (Table 1 and Table 2). In unlogged forest, I found that species evenness was highest in the lowland forest (0.93) compared to lower montane forest (0.71) and upper montane forest (0.79). There was no change from 2005 to 2009. In selectively logged forest, species evenness was highest in the lower montane forest with 0.93 (2005) and 0.92 (2009) to lowland forest with 0.82 (2005) and 0.83 (2009).

Species importance values index differed among trees families and varied across forest type (Appendix 1). In unlogged forest, *Shorea leavis* (Dipterocarpaceae), *Polyalthia* sp. (Annonaceae) and *Tristaniopsis obovata* (Myrtaceae) showed the highest species importance value during both measurements in lowland forest, lower montane forest and upper montane forest, respectively. In selectively logged forest, *Mollatus pinaculatus* (Euphorbiaceae) and *Magnolia candollii* (Magnoliaceae) had the highest species importance value in both lowland forest and lower montane forest (Figure 6).

***Tree aboveground carbon (AGC) stocks***

I found a progressive decrease in tree aboveground carbon stocks with elevation. Aboveground carbon stocks were significantly higher in between unlogged versus selectively logged forest and increased with time (Figure 7).

In unlogged forest, aboveground carbon stocks were highest in lowland forest, followed by lower montane forest and lowest in upper lower montane forest (Table 1; Figure 7). Total aboveground carbon stocks in 2005 was 150.25 Mg C $ha^{-1}$ (95% CI: 150.20 – 150.30) in lowland forest, 108. 29 Mg C $ha^{-1}$ (95% CI: 108.14 – 108.44) in lower montane forest and

91.66 Mg C $ha^{-1}$ in upper montane forest. In 2009, aboveground carbon increased to 19.51 Mg C $ha^{-1}$ in lowland forest, 15.92 Mg C $ha^{-1}$ in the upper lower montane forest and 13.29 Mg C $ha^{-1}$ in the upper montane forest (Table 1; Figure 7). Aboveground carbon from stems in the 21 – 40 cm dbh size class was greater in lowland forest and upper montane forest, and in lower montane forest stem with dbh of 61 – 80 cm had higher aboveground carbon values (Figure 8).

In selectively logged forest, aboveground carbon stocks were higher in lowland than lower montane forest (Table 2). Aboveground carbon stocks during the first measurement in 2005 were 57.45 Mg C $ha^{-1}$ (95% CI: 56.80 – 58.10) in lower montane forest and 74.49 Mg C $ha^{-1}$ (95% CI: 74.41 – 74.57) in lowland forest. In 2009, aboveground carbon stocks increased by 23.86 Mg C $ha^{-1}$ in lowland forest and 13.23 Mg C $ha^{-1}$ in the lower montane forest (Table 2; Figure 7). Trees in the 21 – 40 cm dbh size class made the greatest contribution to aboveground carbon (both measurements) in lowland forest. By contrast, lower montane forest contained slightly greater aboveground carbon in stems in the 21 – 40 cm dbh size class in 2005 and 41 – 60 cm dbh size class in 2009 (Figure 8).

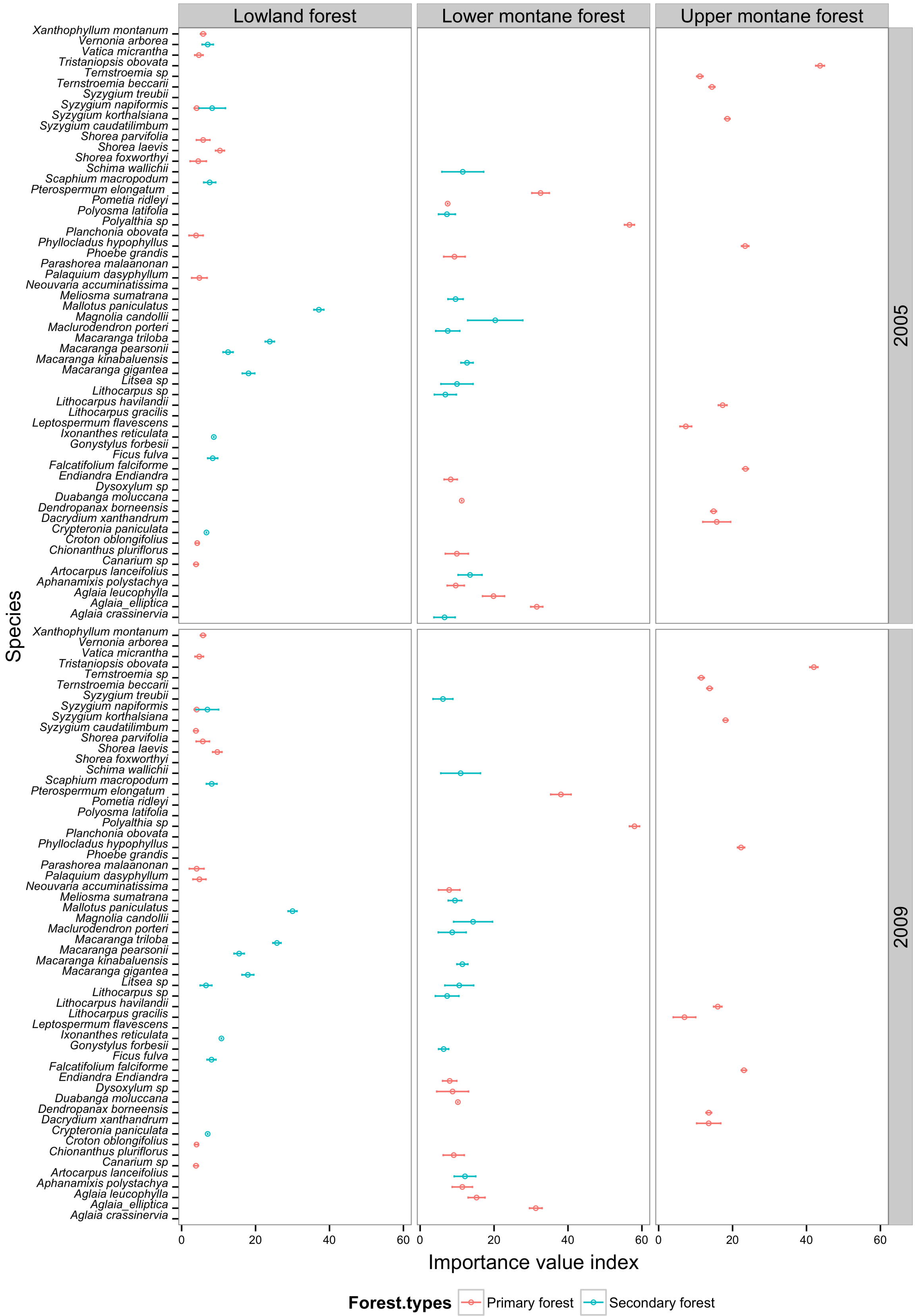


**Figure 6.** Species importance value index (IVI) across forest vegetation zones in 2005 and 2009.

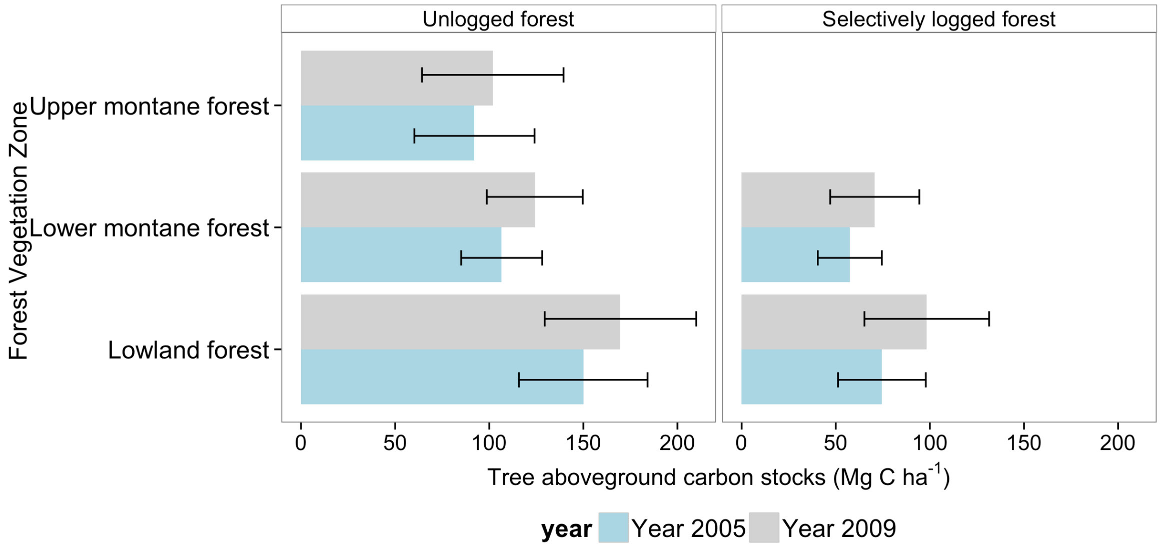


**Figure 7.** Tree aboveground carbon stocks in unlogged and selectively logged forest in 2005 and 2009 with 95% confidence intervals from the glm models.

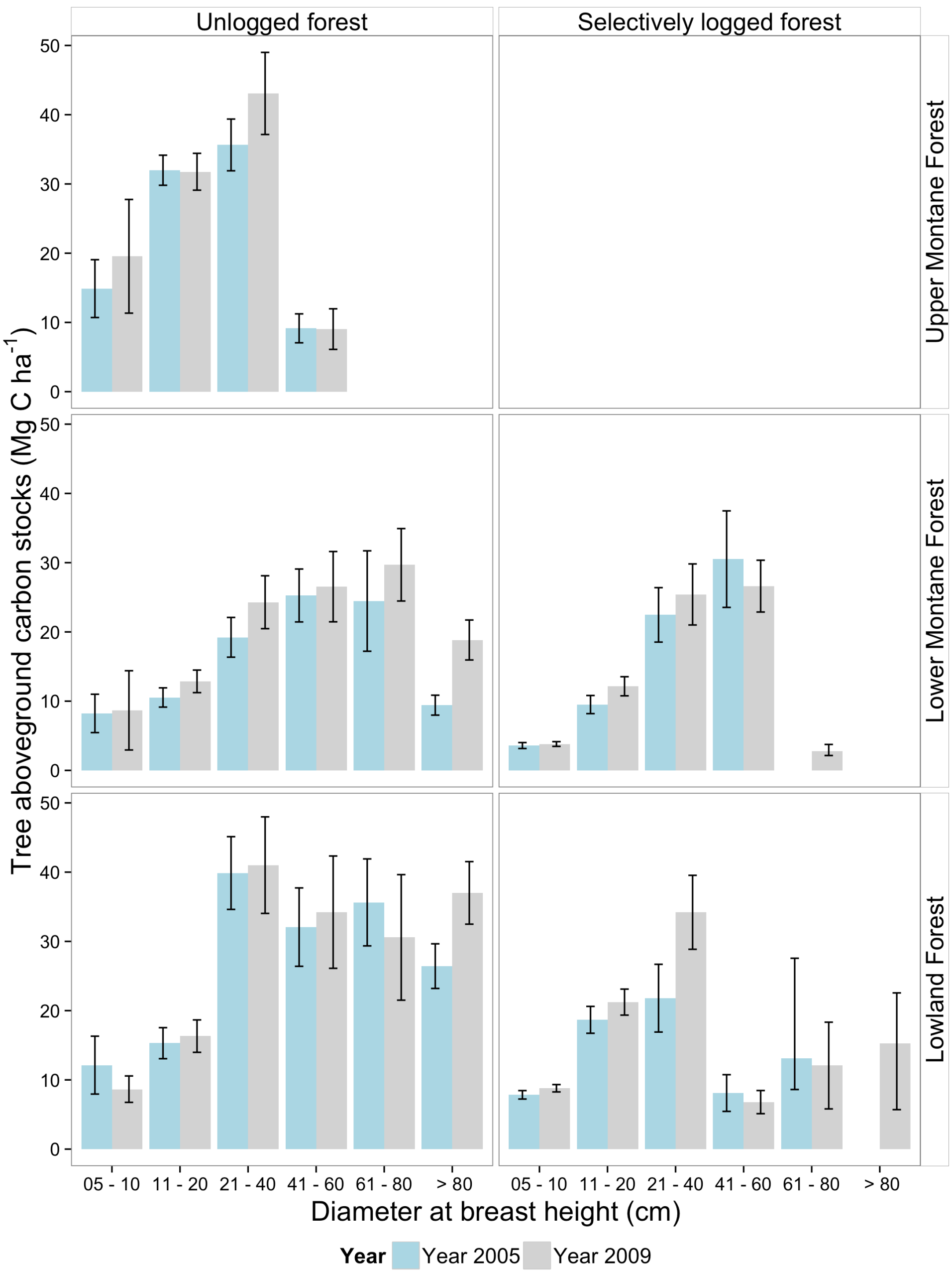


**Figure 8.** Tree aboveground carbon stocks by dbh classes in unlogged and selectively logged lowland forest, lower montane forest and upper montane forest in 2005 and 2009 with 95% confidence intervals from the glm models.

Table 1. Summary of tree diversity along altitudinal zones in Crocker Range Park in unlogged forest.

| Forest types | Lowland forest | | | Lower montane forest | | | Upper montane forest | | |
|---|---|---|---|---|---|---|---|---|---|
| **Particular** | **2005** | **2009** | **Diff.** | **2005** | **2009** | **Diff.** | **2005** | **2009** | **Diff.** |
| No. of family | 45 | 45 | 0 | 24 | 23 | -1 | 27 | 27 | 0 |
| No. of genera | 116 | 116 | 0 | 39 | 38 | -1 | 43 | 42 | -1 |
| No. of species | 265 | 270 | 5 | 50 | 49 | -1 | 75 | 76 | 1 |
| Density (trees $ha^{-1}$) | 1254 | 1252 | -2 | 1024 | 1008 | -16 | 2164 | 2164 | 0 |
| Shannon H' (95% CI) | 5.19 (5.18 – 5.21) | 5.22 (5.2 – 5.23) | 0.03 | 2.76 (2.74 – 2.78) | 2.75 (2.73 – 2.77) | -0.01 | 3.40 (3.38 – 3.41) | 3.44 (3.43 – 45) | 0.04 |
| Evenness (95% CI) | 0.93 (0.93 – 0.93) | 0.93 (0.93 – 0.94) | 0 | 0.71 (0.70 – 0.71) | 0.71 (0.70 – 0.71) | 0 | 0.79 (0.78 – 0.79) | 0.79 (0.79 – 0.80) | 0 |
| Basal area ($m^2$ $ha^{-1}$) (95% CI) | 40.27 (40.26 - 40.28) | 44.53 (44.52 - 44.54) | 4.26 | 30.65 (30.61 – 30.69) | 34.2 (34.15 – 34.25) | 3.55 | 26.85 (26.32 – 26.85) | 29.97 (29.96 – 29.98) | 3.12 |
| Tree AGC (Mg C $ha^{-1}$) (95% CI) | 150.25 (150.20– 150.30) | 169.76 (169.7 – 169.82) | 19.51 | 108.29 (108.14 – 108.44) | 124.21 (124.03 – 124.39) | 15.92 | 91.66 (91.63– 91.68) | 104.95 (104.91 – 104.98) | 13.29 |

Table 2. Summary of tree diversity along altitudinal zones in Crocker Range Park in selectively logged forest.

| Forest types | Lowland forest | | | Lower montane forest | | |
|---|---|---|---|---|---|---|
| **Particular** | **2005** | **2009** | **Diff.** | **2005** | **2009** | **Diff.** |
| No. of family | 39 | 39 | 0 | 36 | 39 | 3 |
| No. of genera | 66 | 71 | 5 | 58 | 62 | 4 |
| No. of species | 101 | 115 | 14 | 97 | 105 | 8 |
| Density (trees $ha^{-1}$) | 1304 | 1496 | 192 | 760 | 832 | 72 |
| Shannon H' (95% CI) | 3.78 (3.76 – 3.8) | 3.95 (3.93 – 3.97) | 0.17 | 4.26 (4.21 – 4.31) | 4.29 (4.25 – 4.34) | 0.03 |
| Evenness (95% CI) | 0.82 (0.81 – 0.82) | 0.83 (0.83 – 0.84) | 0.01 | 0.93 (0.92 – 0.94) | 0.92 (0.91 – 0.93) | -0.01 |
| Basal area ($m^2$ $ha^{-1}$) (95% CI) | 23.02 (23.00 - 23.04) | 29.84 (29.82 - 29.86) | 6.82 | 16.60 (16.41 – 16.78) | 20.58 (20.37– 20.79) | 3.98 |
| Tree AGC (Mg C $ha^{-1}$) (95% CI) | 74.49 (74.41 – 74.57) | 98.35 (98.25 – 98.45) | 23.86 | 57.45 (56.80 – 58.10) | 70.68 (69.96 – 71.40) | 13.23 |

**Table 3**. Tree families across forest vegetation zone in 2005 and 2009 for unlogged forest. Number of stem is given as `n´.

a) Lowland forest

| No | Measurement year 2005 | | | Measurement year 2009 | | |
|---|---|---|---|---|---|---|
| | **Families** | **n** | **Relative density (%)** | **Families** | **n** | **Relative density (%)** |
| 1 | Alangiaceae | 1 | 0.16 | Alangiaceae | 1 | 0.16 |
| 2 | Anacardiaceae | 16 | 2.55 | Anacardiaceae | 17 | 2.72 |
| 3 | Annonaceae | 31 | 4.94 | Annonaceae | 38 | 6.07 |
| 4 | Apocynaceae | 3 | 0.48 | Apocynaceae | 3 | 0.48 |
| 5 | Bombacaceae | 5 | 0.80 | Bombacaceae | 6 | 0.96 |
| 6 | Burseraceae | 21 | 3.35 | Burseraceae | 20 | 3.19 |
| 7 | Celastraceae | 6 | 0.96 | Celastraceae | 5 | 0.80 |
| 8 | Chrysobalanaceae | 1 | 0.16 | Chrysobalanaceae | 1 | 0.16 |
| 9 | Clusiaceae | 11 | 1.75 | Clusiaceae | 11 | 1.76 |
| 10 | Combretaceae | 1 | 0.16 | Combretaceae | 1 | 0.16 |
| 11 | Crypteroniaceae | 1 | 0.16 | Crypteroniaceae | 1 | 0.16 |
| 12 | Ctenolophonaceae | 1 | 0.16 | Ctenolophonaceae | 1 | 0.16 |
| 13 | Dipterocarpaceae | 43 | 6.86 | Dipterocarpaceae | 41 | 6.55 |
| 14 | Ebenaceae | 30 | 4.78 | Ebenaceae | 28 | 4.47 |
| 15 | Euphorbiaceae | 91 | 14.51 | Euphorbiaceae | 92 | 14.70 |
| 16 | Fabaceae | 7 | 1.12 | Fabaceae | 7 | 1.12 |
| 17 | Fagaceae | 21 | 3.35 | Fagaceae | 20 | 3.19 |
| 18 | Flacourtiaceae | 14 | 2.23 | Flacourtiaceae | 13 | 2.08 |
| 19 | Hypericaceae | 5 | 0.80 | Hypericaceae | 5 | 0.80 |
| 20 | Icacinaceae | 12 | 1.91 | Icacinaceae | 11 | 1.76 |
| 21 | Irvingiaceae | 1 | 0.16 | Irvingiaceae | 1 | 0.16 |
| 22 | Lauraceae | 21 | 3.35 | Lauraceae | 20 | 3.19 |
| 23 | Lecythidaceae | 8 | 1.28 | Lecythidaceae | 8 | 1.28 |
| 24 | Loganiaceae | 1 | 0.16 | Loganiaceae | 1 | 0.16 |
| 25 | Magnoliaceae | 5 | 0.80 | Magnoliaceae | 5 | 0.80 |
| 26 | Melastomataceae | 1 | 0.16 | Melastomataceae | 1 | 0.16 |
| 27 | Meliaceae | 32 | 5.10 | Meliaceae | 33 | 5.27 |
| 28 | Moraceae | 22 | 3.51 | Moraceae | 19 | 3.04 |
| 29 | Myristicaceae | 33 | 5.26 | Myristicaceae | 33 | 5.27 |
| 30 | Myrsinaceae | 3 | 0.48 | Myrsinaceae | 3 | 0.48 |
| 31 | Myrtaceae | 49 | 7.81 | Myrtaceae | 49 | 7.83 |
| 32 | Olacaceae | 3 | 0.48 | Olacaceae | 3 | 0.48 |
| 33 | Oleaceae | 4 | 0.64 | Oleaceae | 3 | 0.48 |
| 34 | Polygalaceae | 23 | 3.67 | Polygalaceae | 26 | 4.15 |
| 35 | Proteaceae | 7 | 1.12 | Proteaceae | 6 | 0.96 |
| 36 | Rhamnaceae | 2 | 0.32 | Rhamnaceae | 2 | 0.32 |
| 37 | Rhizophoraceae | 3 | 0.48 | Rhizophoraceae | 2 | 0.32 |
| 38 | Rubiaceae | 23 | 3.67 | Rubiaceae | 22 | 3.51 |
| 39 | Sapindaceae | 24 | 3.83 | Sapindaceae | 24 | 3.83 |
| 40 | Sapotaceae | 15 | 2.39 | Sapotaceae | 17 | 2.72 |
| 41 | Sterculiaceae | 12 | 1.91 | Sterculiaceae | 13 | 2.08 |
| 42 | Theaceae | 2 | 0.32 | Theaceae | 2 | 0.32 |
| 43 | Tiliaceae | 6 | 0.96 | Tiliaceae | 6 | 0.96 |
| 44 | Ulmaceae | 2 | 0.32 | Ulmaceae | 1 | 0.16 |
| 45 | Verbenaceae | 4 | 0.64 | Verbenaceae | 4 | 0.64 |
| | **Total** | **627** | **100** | **Total** | **626** | **100** |

**Table 3**. (Continued)

**b) Lower montane forest**

| No | Measurement year 2005 | | | Measurement year 2009 | | |
|---|---|---|---|---|---|---|
| | **Families** | **n** | **Relative density (%)** | **Families** | **n** | **Relative density (%)** |
| 1 | Alangiaceae | 5 | 1.95 | Alangiaceae | 5 | 1.98 |
| 2 | Annonaceae | 86 | 33.59 | Annonaceae | 86 | 34.13 |
| 3 | Burseraceae | 3 | 1.17 | Burseraceae | 3 | 1.19 |
| 4 | Celastraceae | 1 | 0.39 | Celastraceae | 1 | 0.40 |
| 5 | Clusiaceae | 1 | 0.39 | Clusiaceae | 1 | 0.40 |
| 6 | Elaeocarpaceae | 6 | 2.34 | Elaeocarpaceae | 6 | 2.38 |
| 7 | Euphorbiaceae | 4 | 1.56 | Euphorbiaceae | 4 | 1.59 |
| 8 | Fagaceae | 2 | 0.78 | Fagaceae | 2 | 0.79 |
| 9 | Juglandaceae | 1 | 0.39 | Juglandaceae | 1 | 0.40 |
| 10 | Lauraceae | 18 | 7.03 | Lauraceae | 17 | 6.75 |
| 11 | Lythraceae | 1 | 0.39 | Lythraceae | 1 | 0.40 |
| 12 | Meliaceae | 61 | 23.83 | Meliaceae | 59 | 23.41 |
| 13 | Moraceae | 2 | 0.78 | Moraceae | 2 | 0.79 |
| 14 | Myristicaceae | 1 | 0.39 | Myristicaceae | 1 | 0.40 |
| 15 | Myrtaceae | 10 | 3.91 | Myrtaceae | 10 | 3.97 |
| 16 | Oleaceae | 10 | 3.91 | Oleaceae | 10 | 3.97 |
| 17 | Polygalaceae | 1 | 0.39 | Rubiaceae | 2 | 0.79 |
| 18 | Rubiaceae | 2 | 0.78 | Sapindaceae | 1 | 0.40 |
| 19 | Sapindaceae | 1 | 0.39 | Scyphostegiaceae | 2 | 0.79 |
| 20 | Scyphostegiaceae | 2 | 0.78 | Sterculiaceae | 27 | 10.71 |
| 21 | Sterculiaceae | 27 | 10.55 | Tiliaceae | 4 | 1.59 |
| 22 | Tiliaceae | 4 | 1.56 | Ulmaceae | 3 | 1.19 |
| 23 | Ulmaceae | 3 | 1.17 | Urticaceae | 4 | 1.59 |
| 24 | Urticaceae | 4 | 1.56 | | | |
| | **Total** | **256** | **100** | **Total** | **252** | **100** |

**Table 3**. (Continued)

**c) Upper montane forest**

| | Measurement year 2005 | | | Measurement year 2009 | | |
|---|---|---|---|---|---|---|
| **No** | **Families** | **n** | **Relative density (%)** | **Families** | **n** | **Relative density (%)** |
| 1 | Araliaceae | 47 | 8.25 | Araliaceae | 47 | 7.78 |
| 2 | Clusiaceae | 13 | 2.28 | Clusiaceae | 13 | 2.15 |
| 3 | Cunoniaceae | 1 | 0.18 | Daphniphyllaceae | 3 | 0.50 |
| 4 | Daphniphyllaceae | 3 | 0.53 | Elaeocarpaceae | 4 | 0.66 |
| 5 | Elaeocarpaceae | 4 | 0.70 | Ericaceae | 5 | 0.83 |
| 6 | Ericaceae | 5 | 0.88 | Escalloniaceae | 4 | 0.66 |
| 7 | Escalloniaceae | 4 | 0.70 | Euphorbiaceae | 1 | 0.17 |
| 8 | Euphorbiaceae | 1 | 0.18 | Fagaceae | 40 | 6.62 |
| 9 | Fagaceae | 40 | 7.02 | Lauraceae | 25 | 4.14 |
| 10 | Lauraceae | 25 | 4.39 | Magnoliaceae | 15 | 2.48 |
| 11 | Magnoliaceae | 15 | 2.63 | Melastomataceae | 8 | 1.32 |
| 12 | Melastomataceae | 8 | 1.40 | Meliaceae | 6 | 0.99 |
| 13 | Meliaceae | 6 | 1.05 | Moraceae | 1 | 0.17 |
| 14 | Moraceae | 1 | 0.18 | Myrsinaceae | 10 | 1.66 |
| 15 | Myrsinaceae | 11 | 1.93 | Myrtaceae | 143 | 23.68 |
| 16 | Myrtaceae | 140 | 24.56 | Oleaceae | 1 | 0.17 |
| 17 | Oleaceae | 1 | 0.18 | Pittosporaceae | 1 | 0.17 |
| 18 | Pittosporaceae | 1 | 0.18 | Podocarpaceae | 107 | 17.72 |
| 19 | Podocarpaceae | 107 | 18.77 | Rosaceae | 6 | 0.99 |
| 20 | Rosaceae | 6 | 1.05 | Rubiaceae | 2 | 0.33 |
| 21 | Rubiaceae | 2 | 0.35 | Rutaceae | 24 | 3.97 |
| 22 | Rutaceae | 23 | 4.04 | Sapotaceae | 5 | 0.83 |
| 23 | Sapotaceae | 5 | 0.88 | Symplocaceae | 2 | 0.33 |
| 24 | Symplocaceae | 2 | 0.35 | Saxifragaceae | 1 | 0.17 |
| 25 | Theaceae | 66 | 11.58 | Theaceae | 66 | 10.93 |
| 26 | Winteraceae | 4 | 0.70 | Winteraceae | 4 | 0.66 |
| 27 | Araliaceae | 47 | 8.25 | Araliaceae | 47 | 7.78 |
| | **Total** | **541** | **100** | **Total** | **544** | **100** |

**Table 4**. List of tree family across forest vegetation zone in 2005 and 2009 for selectively logged forest.

**a) Lowland forest**

| No | Measurement year 2005 Families | n | Relative density (%) | Measurement year 2009 Families | n | Relative density (%) |
|---|---|---|---|---|---|---|
| 1 | Alangiaceae | 1 | 0.31 | Alangiaceae | 1 | 0.27 |
| 2 | Anacardiaceae | 2 | 0.61 | Anacardiaceae | 2 | 0.53 |
| 3 | Annonaceae | 3 | 0.92 | Annonaceae | 7 | 1.87 |
| 4 | Araliaceae | 1 | 0.31 | Araliaceae | 1 | 0.27 |
| 5 | Asteraceae | 8 | 2.45 | Asteraceae | 7 | 1.87 |
| 6 | Burseraceae | 2 | 0.61 | Burseraceae | 4 | 1.07 |
| 7 | Chrysobalanaceae | 2 | 0.61 | Chrysobalanaceae | 2 | 0.53 |
| 8 | Clusiaceae | 10 | 3.07 | Clusiaceae | 10 | 2.67 |
| 9 | Crypteroniaceae | 1 | 0.31 | Crypteroniaceae | 1 | 0.27 |
| 10 | Dipterocarpaceae | 6 | 1.84 | Dipterocarpaceae | 6 | 1.60 |
| 11 | Ebenaceae | 1 | 0.31 | Ebenaceae | 2 | 0.53 |
| 12 | Euphorbiaceae | 143 | 43.87 | Euphorbiaceae | 161 | 43.05 |
| 13 | Fabaceae | 2 | 0.61 | Fabaceae | 2 | 0.53 |
| 14 | Fagaceae | 6 | 1.84 | Fagaceae | 6 | 1.60 |
| 15 | Hypericaceae | 2 | 0.61 | Hypericaceae | 3 | 0.80 |
| 16 | Ixonanthaceae | 1 | 0.31 | Ixonanthaceae | 1 | 0.27 |
| 17 | Lauraceae | 20 | 6.13 | Lamiaceae | 1 | 0.27 |
| 18 | Lecythidaceae | 1 | 0.31 | Lauraceae | 22 | 5.88 |
| 19 | Magnoliaceae | 1 | 0.31 | Lecythidaceae | 1 | 0.27 |
| 20 | Melastomataceae | 3 | 0.92 | Magnoliaceae | 1 | 0.27 |
| 21 | Meliaceae | 11 | 3.37 | Melastomataceae | 3 | 0.80 |
| 22 | Moraceae | 20 | 6.13 | Meliaceae | 12 | 3.21 |
| 23 | Myristicaceae | 8 | 2.45 | Moraceae | 25 | 6.68 |
| 24 | Myrsinaceae | 1 | 0.31 | Myristicaceae | 12 | 3.21 |
| 25 | Myrtaceae | 15 | 4.60 | Myrsinaceae | 1 | 0.27 |
| 26 | Olacaceae | 3 | 0.92 | Myrtaceae | 17 | 4.55 |
| 27 | Polygalaceae | 9 | 2.76 | Olacaceae | 3 | 0.80 |
| 28 | Rhizophoraceae | 1 | 0.31 | Polygalaceae | 8 | 2.14 |
| 29 | Rosaceae | 4 | 1.23 | Rhizophoraceae | 1 | 0.27 |
| 30 | Rubiaceae | 9 | 2.76 | Rosaceae | 8 | 2.14 |
| 31 | Sabiaceae | 1 | 0.31 | Rubiaceae | 9 | 2.41 |
| 32 | Sapindaceae | 10 | 3.07 | Sapindaceae | 13 | 3.48 |
| 33 | Sapotaceae | 2 | 0.61 | Sapotaceae | 2 | 0.53 |
| 34 | Sterculiaceae | 8 | 2.45 | Sterculiaceae | 11 | 2.94 |
| 35 | Symplocaceae | 1 | 0.31 | Symplocaceae | 1 | 0.27 |
| 36 | Thymelaeaceae | 1 | 0.31 | Thymelaeaceae | 2 | 0.53 |
| 37 | Tiliaceae | 2 | 0.61 | Tiliaceae | 3 | 0.80 |
| 38 | Ulmaceae | 3 | 0.92 | Ulmaceae | 2 | 0.53 |
| 39 | Verbenaceae | 1 | 0.31 | | | |
| | **Total** | **326** | **100** | **Total** | **374** | **100** |

**Table 4**. (Continued)

**b) Lower montane forest**

| | Measurement year 2005 | | | Measurement year 2009 | | |
|---|---|---|---|---|---|---|
| **No** | **Families** | **n** | **Relative density (%)** | **Families** | **n** | **Relative density (%)** |
| 1 | Alangiaceae | 1 | 0.58 | Alangiaceae | 1 | 0.52 |
| 2 | Anacardiaceae | 1 | 0.58 | Anacardiaceae | 1 | 0.52 |
| 3 | Annonaceae | 5 | 2.89 | Annonaceae | 4 | 2.09 |
| 4 | Apocynaceae | 1 | 0.58 | Apocynaceae | 1 | 0.52 |
| 5 | Burseraceae | 9 | 5.20 | Burseraceae | 11 | 5.76 |
| 6 | Celastraceae | 1 | 0.58 | Celastraceae | 1 | 0.52 |
| 7 | Clusiaceae | 4 | 2.31 | Clusiaceae | 7 | 3.66 |
| 8 | Cornaceae | 6 | 3.47 | Cornaceae | 6 | 3.14 |
| 9 | Crypteroniaceae | 2 | 1.16 | Crypteroniaceae | 2 | 1.05 |
| 10 | Escalloniaceae | 5 | 2.89 | Elaeocarpaceae | 1 | 0.52 |
| 11 | Euphorbiaceae | 22 | 12.72 | Escalloniaceae | 3 | 1.57 |
| 12 | Fagaceae | 8 | 4.62 | Euphorbiaceae | 22 | 11.52 |
| 13 | Flacourtiaceae | 2 | 1.16 | Fagaceae | 7 | 3.66 |
| 14 | Icacinaceae | 1 | 0.58 | Flacourtiaceae | 2 | 1.05 |
| 15 | Lauraceae | 8 | 4.62 | Icacinaceae | 1 | 0.52 |
| 16 | Loganiaceae | 1 | 0.58 | Lamiaceae | 1 | 0.52 |
| 17 | Magnoliaceae | 1 | 0.58 | Lauraceae | 9 | 4.71 |
| 18 | Melastomataceae | 6 | 3.47 | Loganiaceae | 1 | 0.52 |
| 19 | Meliaceae | 13 | 7.51 | Magnoliaceae | 2 | 1.05 |
| 20 | Moraceae | 16 | 9.25 | Melastomataceae | 5 | 2.62 |
| 21 | Myristicaceae | 1 | 0.58 | Meliaceae | 10 | 5.24 |
| 22 | Myrsinaceae | 2 | 1.16 | Moraceae | 16 | 8.38 |
| 23 | Myrtaceae | 13 | 7.51 | Myristicaceae | 2 | 1.05 |
| 24 | Oleaceae | 3 | 1.73 | Myrsinaceae | 2 | 1.05 |
| 25 | Polygalaceae | 6 | 3.47 | Myrtaceae | 15 | 7.85 |
| 26 | Rhamnaceae | 1 | 0.58 | Oleaceae | 3 | 1.57 |
| 27 | Rubiaceae | 13 | 7.51 | Polygalaceae | 9 | 4.71 |
| 28 | Rutaceae | 2 | 1.16 | Rhamnaceae | 1 | 0.52 |
| 29 | Sabiaceae | 7 | 4.05 | Rubiaceae | 14 | 7.33 |
| 30 | Sapindaceae | 3 | 1.73 | Rutaceae | 2 | 1.05 |
| 31 | Sapotaceae | 2 | 1.16 | Sabiaceae | 9 | 4.71 |
| 32 | Thymelaeaceae | 2 | 1.16 | Sapindaceae | 3 | 1.57 |
| 33 | Ulmaceae | 3 | 1.73 | Sapotaceae | 1 | 0.52 |
| 34 | Verbenaceae | 2 | 1.16 | Saxifragaceae | 2 | 1.05 |
| 35 | Alangiaceae | 1 | 0.58 | Theaceae | 1 | 0.52 |
| 36 | Anacardiaceae | 1 | 0.58 | Thymelaeaceae | 9 | 4.71 |
| 37 | | | | Tiliaceae | 1 | 0.52 |
| 38 | | | | Ulmaceae | 2 | 1.05 |
| 39 | | | | Verbenaceae | 1 | 0.52 |
| | **Total** | **173** | **100** | **Total** | **191** | **100** |

**Discussion**

I found three main patterns: Aboveground carbon decreased with increasing altitude and had been reduced by selective logging. Tree diversity also decreased with increasing altitude.

*Variation of forest structure along altitude*

The number of tree stems in unlogged forest was higher in the upper montane forest and lower in lower montane forest and lowland forest, where tree stems 5 to 40 cm dbh made the greatest contribution to density. Elevation and regional climate, shows the change in vegetation structure with elevation vary greatly (Grubb, 1977; Bruijnzeel and Veneklaas, 1998; Bruijnzeel, 2002). Results indicated that the density of smaller trees was higher at higher altitudes but basal area decreased, which is similar to the pattern observed by Aiba and Kitayama (1999) near the study area.

In selectively logged forest tree density and basal area were higher in lowland forest compared to lower montane forest. Lower tree density and basal area in selectively logged forest compared to unlogged forest is likely the result of logging in the 1980s. Differences in forest structure between unlogged and selectively logged forest have been correlated with logging intensity elsewhere (Bertault and Sist, 1997; Pinard *et al.*, 2000). Tree density and basal area in lowland forest changed more than the lower montane forest indicating that lowland forest was more heavily logged than forest at higher elevations. Recovery of forest structure was higher in lowland forest as compared to lower montane forest.

Changes in soil type and nutrient status and microclimate may contribute to the change of species diversity along the elevation gradient. In unlogged areas, lowland forest with fertile, well-drained soil showed higher species diversity compared to other vegetation zones. By contrast, selectively logged lower montane forest contained higher species diversity than selectively logged lowland forest, which is indicative of higher logging disturbance in lowland forest.

*Variation of Tree aboveground carbon stocks along elevation gradient*

Forests keep carbon out of the atmosphere and it has been estimated that forests contain approximately 40% of total terrestrial carbon (Powell, *et al,* 2002). I found that aboveground carbon stocks decline with increasing elevation. These results agree with other studies in the tropics, where aboveground carbon decreased with increased of elevation (Alves *et al.*, 2010; Laumonier *et al.*, 2010; Aiba and Kitayama, 1999; Kitayama and Aiba, 2002; Moser *et al*., 2007; Leuschner *et al*., 2007). Although aboveground carbon declined with increased elevation, I found that unlogged lower montane forest and upper montane forest ecosystem stored more carbon than selectively logged lowland forest.

In addition, the elevation variation in live aboveground carbon stocks suggests large spatial variability over forest along an altitudinal gradients in Malaysia, clearly indicating that it is important to consider altitude differences in carbon stocks when evaluating the role of this endangered tropical ecosystem in the global carbon cycle. Forest biomass has a large potential for temporary and long-term carbon storage (Houghton, 2005). The relationship between diversity and C stocks is still undetermined and in correlational studies its relationship depends on other factors and features including altitude, physiographic factors, etc.

This study provides some data on the altitudinal distributions of plants in this region, but further data collection is needed for a better study of plant species distributions that can be used as a baseline to assess other ecosystem functioning impacts in this area. Further study is needed to understand the changes of forest structure at different altitudes and would be interesting in order to identify key factors that cause changes in forest types. It would also be interesting to know how the success of regeneration varies along the altitudinal gradient from lowland to upper montane forest. The addition of important components of forest diversity and biomass, including coarse wood debris, litter, saplings (1 – 10 cm dbh), seedlings, herbs and shrubs, would be useful in order to develop better estimates and provide more accurate estimate of forest structure and carbon stocks, which are important for long term monitoring. Given the sampling design of this study, the estimate of carbon stocks presented here might not be comparable to other studies due to the different sizes of the plots. However, the carbon stock estimation carried out here makes it possible to improve my ability to manage the unlogged and selectively logged forest areas at different altitudes.

One main caveat over the estimates of carbon stocks presented here is that they are based on the use of a single allometric equation (Basuki 2009). It may be that different allometric equations may be needed for forest vegetation at different altitudes. However, at the time of the study the Basuki equations were the best available.

**Conclusion**

This chapter focused on understanding differences in forest structure and aboveground carbon stocks along an altitudinal gradient. Results showed that forest structure and carbon storage varied both between forest types (altitude) and logging status. Forest structure changed and aboveground carbon stocks declined with increasing altitude. Lowland forest showed the greatest recovery in terms of aboveground carbon stocks, adding >50% to carbon stocks between the 2005 and 2009 survey. Aboveground carbon stocks declined between the survey dates in the lower montane forest, probably due to illegal timber felling. Aboveground carbon stocks were maintained in the upper montane forest most likely as this forest type was subject to lower levels of disturbance.

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## Appendix1

**Table 5.** List of species with number of stem (n) and important value index (I.V.I) along the altitudinal zone in unlogged forest.

| Family/Species | | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| ALANGIACEAE | | | | | | | | | | | | | |
| 1 | Alangium javanicum | 1 | 0.47 (0.47 – 0.47) | 1 | 0.47 (0.47 – 0.47) | 2 | 2.32 (1.18 – 3.46) | 2 | 2.37 (1.21 – 3.53) | – | – | – | – |
| 2 | Alangium sp. | – | | – | – | 3 | 4.28 (2.41 – 6.14) | 3 | 4.33 (2.44 – 6.22) | – | – | – | – |
| ANACARDIACEAE | | | | | | | | | | | | | |
| 1 | Gluta wallichii | 7 | 2.66 (2.03 – 3.3) | 7 | 2.72 (2.07 – 3.37) | – | – | – | – | – | – | – | – |
| 2 | Melanochyla castaneifolia | 3 | 1.13 (0.64 – 1.63) | 3 | 1.19 (0.67 – 1.71) | – | – | – | – | – | – | – | – |
| 3 | Melanochyla sp. | 5 | 1.52 (1.05 – 2) | 5 | 1.56 (1.07 – 2.06) | – | – | – | – | – | – | – | – |
| 4 | Swintonia acuta | 1 | 2.56 (2.56 – 2.56) | 1 | 2.38 (2.38 – 2.38) | – | – | – | – | – | – | – | – |
| 5 | Swintonia minutalata | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| ANNONACEAE | | | | | | | | | | | | | |
| 1 | Desmos dumosus | 3 | 1.08 (0.61 – 1.55) | 3 | 0.92 (0.52 – 1.32) | – | – | – | – | – | – | – | – |
| 2 | Goniothalamus clemensii | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 3 | Gonystylus nervosus | – | – | 1 | 0.96 (0.96 – 0.96) | – | – | – | – | – | – | – | – |
| 4 | Neouvaria accuminatissima | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | 4 | 4.38 (2.77 – 5.99) | 4 | 7.81 (4.94 – 10.69) | – | – | – | – |
| 5 | Polyalthia canangioides | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 6 | Polyalthia cauliflora | 8 | 2.37 (1.86 – 2.88) | 11 | 3.14 (2.63 – 3.65) | – | – | – | – | – | – | – | – |
| 7 | Polyalthia chrysotricha | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 8 | Polyalthia longipes | 1 | 0.9 (0.9 – 0.9) | 2 | 0.74 (0.38 – 1.11) | – | – | – | – | – | – | – | – |
| 9 | Polyalthia obliqua | 3 | 0.97 (0.55 – 1.39) | 3 | 0.99 (0.56 – 1.42) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ANNONACEAE (Continued) | | | | | | | | | | | | | |
| 10 | Polyalthia sp. | 2 | 0.82 (0.42 – 1.22) | 3 | 1.22 (0.69 – 1.74) | 82 | 56.63 (55.29 – 57.96) | 82 | 58.04 (56.67 – 59.41) | – | – | – | – |
| 11 | Polyalthia sumatrana | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 12 | Sageraea lanceolata | 7 | 2.84 (2.16 – 3.53) | 7 | 2.92 (2.22 – 3.62) | – | – | – | – | – | – | – | – |
| 13 | Sageraea sp. | 1 | 0.45 (0.45 – 0.45) | 1 | 0.45 (0.45 – 0.45) | – | – | – | – | – | – | – | – |
| 14 | Xylopia dehiscens | 1 | 0.38 (0.38 – 0.38) | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | – | – | – | – |
| 15 | Xylopia malayana | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| ANACARDIACEAE | | | | | | | | | | | | | |
| 1 | Gluta wallichii | 7 | 2.66 (2.03 – 3.3) | 7 | 2.72 (2.07 – 3.37) | – | – | – | – | – | – | – | – |
| 2 | Melanochyla castaneifolia | 3 | 1.13 (0.64 – 1.63) | 3 | 1.19 (0.67 – 1.71) | – | – | – | – | – | – | – | – |
| 3 | Melanochyla sp. | 5 | 1.52 (1.05 – 2) | 5 | 1.56 (1.07 – 2.06) | – | – | – | – | – | – | – | – |
| 4 | Swintonia acuta | 1 | 2.56 (2.56 – 2.56) | 1 | 2.38 (2.38 – 2.38) | – | – | – | – | – | – | – | – |
| 5 | Swintonia minutalata | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| APOCYNACEAE | | | | | | | | | | | | | |
| 1 | Alstonia angustiloba | 2 | 0.74 (0.38 – 1.1) | 2 | 0.76 (0.39 – 1.13) | – | – | – | – | – | – | – | – |
| 2. | Tabernaemontana macrocarpa | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| ARALIACEAE | | | | | | | | | | | | | |
| 1 | Dendropanax borneensis | – | – | – | – | – | – | – | – | 37 | 14.76 (14 – 15.52) | 35 | 13.63 (12.89 – 14.37) |
| 2 | Gastonia serratifolia | – | – | – | – | – | – | – | – | 14 | 5.97 (5.19 – 6.74) | 17 | 6.52 (5.81 – 7.23) |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| BOMBACACEAE | | | | | | | | | | | | | |
| 1 | Durio affinis | 4 | 1.52 (0.96 – 2.08) | 4 | 1.6 (1.01 – 2.18) | – | – | – | – | – | – | – | – |
| 2 | Durio grandiflorus | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 3 | Durio zebentus | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| BURSERACEAE | | | | | | | | | | | | | |
| 1 | Canarium asperum | 2 | 1.6 (0.81 – 2.38) | 2 | 1.56 (0.79 – 2.32) | – | – | – | – | – | – | – | – |
| 2 | Canarium caudatum | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | – | – | – | – | – | – |
| 3 | Canarium cauliflora | 1 | 1.05 (1.05 – 1.05) | 1 | 1.03 (1.03 – 1.03) | – | – | – | – | – | – | – | – |
| 4 | Canarium denticulatum | 1 | 0.44 (0.44 – 0.44) | 1 | 0.44 (0.44 – 0.44) | 3 | 6.03 (3.4 – 8.66) | 3 | 5.88 (3.32 – 8.44) | – | – | – | – |
| 5 | Canarium megalanthum | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 6 | Canarium merrillii | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 7 | Canarium ovatum | 1 | 0.7 (0.7 – 0.7) | 1 | 0.69 (0.69 – 0.69) | – | – | – | – | – | – | – | – |
| 8 | Canarium sp. | 11 | 3.91 (3.28 – 4.55) | 11 | 3.99 (3.34 – 4.63) | – | – | – | – | – | – | – | – |
| 9 | Dacryodes costata | 2 | 0.79 (0.4 – 1.18) | 2 | 0.81 (0.41 – 1.21) | – | – | – | – | – | – | – | – |
| CELASTRACEAE | | | | | | | | | | | | | |
| 1 | Euonymus castaneifolius | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 2 | Lophopetalum beccarianum | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 3 | Lophopetalum glabrum | 4 | 1.35 (0.86 – 1.85) | 4 | 1.4 (0.88 – 1.91) | – | – | – | – | – | – | – | – |
| 4 | Lophopetalum javanicum | – | – | – | – | 1 | 1.09 (1.09 – 1.09) | 1 | 0.42 (0.42 – 0.42) | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| CHRYSOBALANACEAE | | | | | | | | | | | | | |
| 1 | Parinari canarioides | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| CLUSIACEAE | | | | | | | | | | | | | |
| 1 | Calophyllum blancoi | 1 | 0.5 (0.5 – 0.5) | 1 | 0.51 (0.51 – 0.51) | – | – | – | – | – | – | – | – |
| 2 | Calophyllum ferrugineum | – | – | – | – | – | – | – | – | 1 | 1.19 (1.19 – 1.19) | 1 | 1.15 (1.15 – 1.15) |
| 3 | Calophyllum gracilipes | 2 | 0.9 (0.46 – 1.34) | 2 | 0.91 (0.46 – 1.36) | – | – | – | – | – | – | – | – |
| 4 | Calophyllum soulatrii | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 5 | Calophyllum sp. | – | – | – | – | – | – | – | – | 5 | 3.42 (2.35 – 4.49) | 5 | 3.28 (2.25 – 4.31) |
| 6 | Calophyllum venulosum | – | – | – | – | – | – | – | – | 1 | 0.66 (0.66 – 0.66) | 1 | 0.63 (0.63 – 0.63) |
| 7 | Garcinia caudiculata | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | 1 | 0.59 (0.59 – 0.59) | 1 | 0.56 (0.56 – 0.56) |
| 8 | Garcinia mangostana | 2 | 0.81 (0.41 – 1.2) | 3 | 1 (0.56 – 1.43) | – | – | – | – | – | – | – | – |
| 9 | Garcinia minimiflora | – | – | – | – | – | – | – | – | 1 | 0.5 (0.5 – 0.5) | 1 | 0.48 (0.48 – 0.48) |
| 10 | Garcinia parvifolia | 3 | 1.13 (0.64 – 1.62) | 2 | 0.78 (0.4 – 1.17) | – | – | – | – | – | – | – | – |
| 11 | Garcinia sp. | – | – | – | – | – | – | – | – | 4 | 2.26 (1.43 – 3.09) | 5 | 2.34 (1.61 – 3.08) |
| 12 | Garcinia tetragonus | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 13 | Garcinia trianii | – | – | – | – | 1 | 1.13 (1.13 – 1.13) | 1 | 1.16 (1.16 – 1.16) | – | – | – | – |
| COMBRETACEAE | | | | | | | | | | | | | |
| 1 | Terminalia foetidissima | 1 | 0.65 (0.65 – 0.65) | 1 | 0.65 (0.65 – 0.65) | – | – | – | – | – | – | – | – |
| CRYPTERONIACEAE | | | | | | | | | | | | | |
| 1 | Crypteronia paniculata | 1 | 2.48 (2.48 – 2.48) | 1 | 2.76 (2.76 – 2.76) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| CTENOLOPHONACEAE | | | | | | | | | | | | | |
| 1 | Ctenolophon parvifolius | 1 | 0.43 (0.43 – 0.43) | 1 | 0.48 (0.48 – 0.48) | – | – | – | – | – | – | – | – |
| CUNONIACEAE | | | | | | | | | | | | | |
| 1 | Weinmannia blumei | – | – | – | – | – | – | – | – | 1 | 0.55 (0.55 – 0.55) | – | – |
| DAPHNIPHYLLACEAE | | | | | | | | | | | | | |
| 1 | Daphniphyllum borneense | – | – | – | – | – | – | – | – | 2 | 1.19 (0.6 – 1.77) | 2 | 1.13 (0.57 – 1.68) |
| 2 | Daphniphyllum laurinum | – | – | – | – | – | – | – | – | 1 | 0.51 (0.51 – 0.51) | 1 | 0.48 (0.48 – 0.48) |
| DIPTEROCARPACEAE | | | | | | | | | | | | | |
| 1 | Anisoptera laevis | 1 | 3.11 (3.11 – 3.11) | 1 | 2.67 (2.67 – 2.67) | – | – | – | – | – | – | – | – |
| 2 | Dipterocarpus caudatus | 1 | 0.61 (0.61 – 0.61) | 1 | 0.41 (0.41 – 0.41) | – | – | – | – | – | – | – | – |
| 3 | Parashorea malaanonan | 2 | 0.77 (0.39 – 1.15) | 2 | 4.15 (2.12 – 6.18) | – | – | – | – | – | – | – | – |
| 4 | Shorea faguetiana | 1 | 0.58 (0.58 – 0.58) | 1 | 0.58 (0.58 – 0.58) | – | – | – | – | – | – | – | – |
| 5 | Shorea fallax | 1 | 0.87 (0.87 – 0.87) | 1 | 0.67 (0.67 – 0.67) | – | – | – | – | – | – | – | – |
| 6 | Shorea foxworthyi | 2 | 4.56 (2.33 – 6.8) | 2 | 3.1 (1.58 – 4.62) | – | – | – | – | – | – | – | – |
| 7 | Shorea gibbosa | 1 | 0.4 (0.4 – 0.4) | 1 | 0.22 (0.22 – 0.22) | – | – | – | – | – | – | – | – |
| 8 | Shorea laevis | 16 | 10.49 (9.28 – 11.69) | 14 | 9.86 (8.57 – 11.14) | – | – | – | – | – | – | – | – |
| 9 | Shorea macroptera | 1 | 0.39 (0.39 – 0.39) | 1 | 0.43 (0.43 – 0.43) | – | – | – | – | – | – | – | – |
| 10 | Shorea parvifolia | 5 | 5.9 (4.05 – 7.75) | 5 | 5.87 (4.03 – 7.71) | – | – | – | – | – | – | – | – |
| 11 | Shorea pauciflora | 1 | 0.51 (0.51 – 0.51) | – | – | – | – | – | – | – | – | – | – |
| 12 | Shorea rubra | 1 | 3.19 (3.19 – 3.19) | 1 | 3.09 (3.09 – 3.09) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| DIPTEROCARPACEAE (Continued) | | | | | | | | | | | | | |
| 13 | Shorea sp. | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 14 | Vatica albiramis | 1 | 0.74 (0.74 – 0.74) | 1 | 0.74 (0.74 – 0.74) | – | – | – | – | – | – | – | – |
| 15 | Vatica micrantha | 7 | 4.7 (3.57 – 5.83) | 7 | 4.89 (3.71 – 6.06) | – | – | – | – | – | – | – | – |
| 16 | Vatica umbonata | 2 | 0.96 (0.49 – 1.43) | 2 | 0.97 (0.49 – 1.44) | – | – | – | – | – | – | – | – |
| EBENACEAE | | | | | | | | | | | | | |
| 1 | Diospyros areolata | 2 | 0.83 (0.42 – 1.23) | 2 | 0.84 (0.43 – 1.25) | – | – | – | – | – | – | – | – |
| 2 | Diospyros borneensis | 1 | 0.39 (0.39 – 0.39) | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | – | – | – | – |
| 3 | Diospyros cauliflora | 3 | 1.1 (0.62 – 1.58) | 3 | 0.94 (0.53 – 1.35) | – | – | – | – | – | – | – | – |
| 4 | Diospyros curranii | 3 | 1.75 (0.99 – 2.51) | 3 | 1.52 (0.86 – 2.18) | – | – | – | – | – | – | – | – |
| 5 | Diospyros densa | 2 | 0.82 ( 0.42 – 1.22) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 6 | Diospyros discocalyx | 8 | 2.87 (2.26 – 3.49) | 7 | 2.78 (2.11 – 3.45) | – | – | – | – | – | – | – | – |
| 7 | Diospyros ferruginescenns | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 8 | Diospyros foxworthyi | 2 | 0.73 (0.37 – 1.09) | 2 | 0.75 (0.38 – 1.12) | – | – | – | – | – | – | – | – |
| 9 | Diospyros frutescens | 5 | 1.9 (1.31 – 2.5) | 4 | 1.6 (1.01 – 2.19) | – | – | – | – | – | – | – | – |
| 10 | Diospyros lanceifolia | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 11 | Diospyros oligantha | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 12 | Diospyros sp. | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 13 | Diospyros virgata | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| ELAEOCARPACEAE | | | | | | | | | | | | | |
| 1 | Elaeocarpus angustipes | – | – | – | – | – | – | – | – | 1 | 0.55 (0.55 – 0.55) | 1 | 0.52 (0.52 – 0.52) |
| 2 | Elaeocarpus kinabaluensis | – | – | – | – | – | – | – | – | 2 | 1 (0.51 – 1.48) | 2 | 0.94 (0.48 – 1.4) |
| 3 | Elaeocarpus knuthii | – | – | – | – | – | – | – | – | 1 | 0.51 (0.51 – 0.51) | 1 | 0.48 (0.48 – 0.48) |
| 4 | Sloanea sigun | – | – | – | – | 6 | 7.2 (5.24 – 9.15) | – | – | – | – | – | – |
| 5 | Sloanea Sloanea sigun | – | – | – | – | – | – | 6 | 7.25 (5.28 – 9.22) | – | – | – | – |
| ERICACEAE | | | | | | | | | | | | | |
| 1 | Vaccinium bancanum | – | – | – | – | – | – | – | – | 5 | 2.79 (1.92 – 3.67) | 5 | 2.65 (1.82 – 3.48) |
| ESCALLONIACEAE | | | | | | | | | | | | | |
| 1 | Polyosma sp. | – | – | – | – | – | – | – | – | 4 | 2.13 (1.35 – 2.92) | – | – |
| EUPHORBIACEAE | | | | | | | | | | | | | |
| 1 | Antidesma leucopodum | 7 | 2.19 (1.66 – 2.71) | 7 | 2.05 (1.56 – 2.54) | – | – | – | – | – | – | – | – |
| 2 | Antidesma montanum | 1 | 0.39 (0.39 – 0.39) | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | – | – | – | – |
| 3 | Antidesma sp. | 1 | 0.4 (0.4 – 0.4) | 1 | 0.41 (0.41 – 0.41) | – | – | – | – | – | – | – | – |
| 4 | Aporusa cf.elmeri | – | – | – | – | 1 | 1.41 (1.41 – 1.41) | 1 | 1.4 (1.4 – 1.4) | – | – | – | – |
| 5 | Aporusa elmeri | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | 1 | 1.65 (1.65 – 1.65) | 1 | 1.63 (1.63 – 1.63) | – | – | – | – |
| 6 | Aporusa subcaudata | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 7 | Baccaurea kunstleri | 1 | 0.42 (0.42 – 0.42) | 1 | 0.43 (0.43 – 0.43) | – | – | – | – | – | – | – | – |
| 8 | Baccaurea lanceolata | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | 1 | 1.11 (1.11 – 1.11) | 1 | 1.14 (1.14 – 1.14) | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EUPHORBIACEAE (Continued) | | | | | | | | | | | | | |
| 9 | Baccaurea macrocarpa | 2 | 1.04 (0.53 – 1.55) | 2 | 1.04 (0.53 – 1.55) | – | – | – | – | – | – | – | – |
| 10 | Baccaurea membranacea | – | – | 1 | 0.17 (0.17 – 0.17) | – | – | – | – | – | – | – | – |
| 11 | Baccaurea pubera | 2 | 0.74 (0.38 – 1.1) | 2 | 0.76 (0.39 – 1.14) | – | – | – | – | – | – | – | – |
| 12 | Baccaurea sp. | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 13 | Baccaurea tetrandra | 8 | 3.01 (2.37 – 3.66) | 8 | 2.87 (2.26 – 3.49) | – | – | – | – | – | – | – | – |
| 14 | Blumeodendron concolor | 2 | 0.73 (0.37 – 1.08) | 2 | 0.75 (0.38 – 1.12) | – | – | – | – | – | – | – | – |
| 15 | Blumeodendron sp. | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 16 | Blumeodendron tokbrai | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.22 (1.22 – 1.22) | – | – | – | – |
| 17 | Cleistanthus bokonensis | 7 | 2.52 (1.92 – 3.13) | 7 | 2.39 (1.82 – 2.97) | – | – | – | – | – | – | – | – |
| 18 | Cleistanthus myrianthus | 10 | 3.72 (3.07 – 4.38) | 10 | 3.82 (3.15 – 4.5) | – | – | – | – | – | – | – | – |
| 19 | Croton oblongifolius | 15 | 4.21 (3.7 – 4.73) | 15 | 4.11 (3.61 – 4.61) | – | – | – | – | – | – | – | – |
| 20 | Croton oblongus | 2 | 0.77 (0.39 – 1.15) | 2 | 0.79 (0.4 – 1.18) | – | – | – | – | – | – | – | – |
| 21 | Dimorphocalyx malayanus | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 22 | Drypetes kikir | 1 | 0.56 (0.56 – 0.56) | 1 | 0.57 (0.57 – 0.57) | – | – | – | – | – | – | – | – |
| 23 | Drypetes longifolia | 1 | 0.39 (0.39 – 0.39) | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | – | – | – | – |
| 24 | Drypetes polyneura | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 25 | Drypetes sp. | 3 | 1.09 (0.61 – 1.56) | 3 | 1.15 (0.65 – 1.65) | – | – | – | – | – | – | – | – |
| 26 | Glochidion sp. | – | – | – | – | – | – | – | – | 1 | 0.52 (0.52 – 0.52) | 1 | 0.49 (0.49 – 0.49) |
| 27 | Koilodepas laevigatum | 9 | 3.57 (2.88 – 4.26) | 8 | 3.21 (2.52 – 3.89) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| EUPHORBIACEAE (Continued) | | | | | | | | | | | | | |
| 28 | Macaranga hypoleuca | – | – | 1 | 0.17 (0.17 – 0.17) | – | – | – | – | – | | – | – |
| 29 | Macaranga lowii | 1 | 0.36 (0.36 – 0.36) | 1 | 0.17 (0.17 – 0.17) | – | – | – | – | – | – | – | – |
| 30 | Mallotus caudatus | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 31 | Mallotus korthalsii | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 32 | Mallotus stipularis | 4 | 1.18 (0.75 – 1.62) | 4 | 1.2 (0.76 – 1.64) | – | – | – | – | – | – | – | – |
| 33 | Microdesmis caseariaefolia | 2 | 0.74 (0.38 – 1.1) | 2 | 0.76 (0.39 – 1.14) | – | – | – | – | – | – | – | – |
| 34 | Pimeleodendron griffithianum | 2 | 0.88 (0.45 – 1.31) | 2 | 0.69 (0.35 – 1.03) | – | – | – | – | – | – | – | – |
| 35 | Ptychopxis arborea | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 36 | Suregada glomerulata | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – | – | – |
| FABACEAE | | | | | | | | | | | | | |
| 1 | Archidendron borneensis | 1 | 0.89 (0.89 – 0.89) | 1 | 0.88 (0.88 – 0.88) | – | – | – | – | – | | – | – |
| 2 | Archidendron ellipticum | 2 | 0.76 (0.39 – 1.13) | 2 | 0.78 (0.4 – 1.16) | – | – | – | – | – | – | – | – |
| 3 | Dialium indum | 1 | 0.51 (0.51 – 0.51) | 1 | 0.33 (0.33 – 0.33) | – | – | – | – | – | – | – | – |
| 4 | Parkia javanica | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 5 | Sindora irpicina | 2 | 0.73 (0.37 – 1.09) | 2 | 0.76 (0.39 – 1.13) | – | – | – | – | – | – | – | – |
| FAGACEAE | | | | | | | | | | | | | |
| 1 | Castanopsis evansii | 1 | 0.6 (0.6 – 0.6) | 1 | 0.7 (0.7 – 0.7) | – | – | – | – | – | | – | – |
| 2 | Castanopsis hypophoenicea | – | – | – | – | 1 | 1.28 (1.28 – 1.28) | 1 | 1.4 (1.4 – 1.4) | – | – | – | – |
| 3 | Castanopsis megacarpa | – | – | – | – | – | – | – | – | 1 | 0.5 (0.5 – 0.5) | 1 | 0.47 (0.47 – 0.47) |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| FAGACEAE (Continued) | | | | | | | | | | | | | |
| 4 | Lithocarpus bullatus | – | – | – | – | – | – | – | – | 3 | 1.27 (0.72 – 1.82) | 3 | 1.21 (0.68 – 1.74) |
| 5 | Lithocarpus caudatifolius | 4 | 1.94 (1.23 – 2.65) | 4 | 2.22 (1.41 – 3.04) | – | – | – | – | – | | – | – |
| 6 | Lithocarpus cf.dasystachyus | – | – | – | – | 1 | 2.92 (2.92 – 2.92) | 1 | 2.8 (2.8 – 2.8) | – | – | – | – |
| 7 | Lithocarpus clementianus | – | – | – | – | – | – | – | – | 1 | 0.52 (0.52 – 0.52) | 1 | 0.5 (0.5 – 0.5) |
| 8 | Lithocarpus ewyckii | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 9 | Lithocarpus gracilis | 1 | 1.02 (1.02 – 1.02) | 1 | 1.07 (1.07 – 1.07) | – | – | – | – | 2 | 3.88 (1.98 – 5.78) | 3 | 4.27 (2.41 – 6.13) |
| 10 | Lithocarpus hatusimae | 3 | 1.95 (1.1 – 2.79) | 3 | 1.87 (1.06 – 2.69) | – | – | – | – | – | – | – | – |
| 11 | Lithocarpus havilandii | – | – | – | – | – | – | – | – | 28 | 17.09 (15.93 – 18.24) | 27 | 16.21 (15.08 – 17.35) |
| 12 | Lithocarpus leptogyne | 2 | 0.79 (0.4 – 1.18) | 2 | 0.81 (0.42 – 1.21) | – | – | – | – | – | | – | – |
| 13 | Lithocarpus lucidus | 4 | 1.38 (0.87 – 1.88) | 3 | 1.24 (0.7 – 1.78) | – | – | – | – | – | – | – | – |
| 14 | Lithocarpus pseudokunstleri | 2 | 1.02 (0.52 – 1.53) | 2 | 1.02 (0.52 – 1.52) | – | – | – | – | – | – | – | – |
| 15 | Lithocarpus sp. | 2 | 0.73 (0.37 – 1.09) | 2 | 0.76 (0.39 – 1.14) | – | – | – | – | – | – | – | – |
| 16 | Quercus lineata | 1 | 0.71 (0.71 – 0.71) | 1 | 0.73 (0.73 – 0.73) | – | – | – | – | – | – | – | – |
| 17 | Trigonobalanus sp. | – | – | – | – | – | – | – | – | 1 | 0.6 (0.6 – 0.6) | 1 | 0.57 (0.57 – 0.57) |
| 18 | Trigonobalanus verticillata | – | – | – | – | – | – | – | – | 9 | 5.21 (4.2 – 6.22) | 6 | 3.64 (2.65 – 4.63) |
| FLACOURTIACEAE | | | | | | | | | | | | | |
| 1 | Flacourtia sp. | 1 | 0.41 (0.41 – 0.41) | 1 | 0.42 (0.42 – 0.42) | – | – | – | – | – | – | – | – |
| 2 | Hydnocarpus anomalus | 2 | 1.2 (0.61 – 1.79) | 2 | 1.27 (0.65 – 1.89) | – | – | – | – | – | – | – | – |
| 3 | Hydnocarpus polypetalus | 5 | 1.44 (0.99 – 1.89) | 4 | 1.31 (0.83 – 1.79) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| Family/Species | | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| FLACOURTIACEAE (Continued) | | | | | | | | | | | | | |
| 4 | Hydnocarpus woodii | 6 | 3.67 (2.67 – 4.67) | 6 | 3.88 (2.82 – 4.93) | – | – | – | – | – | – | – | – |
| HYPERICACEAE | | | | | | | | | | | | | |
| 1 | Cratoxylum arborescens | 4 | 1.86 (1.18 – 2.54) | 4 | 1.88 (1.19 – 2.57) | – | – | – | – | – | – | – | – |
| 2 | Cratoxylum cochinchinense | 1 | 0.51 (0.51 – 0.51) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |
| ICACINACEAE | | | | | | | | | | | | | |
| 1 | Gonocaryum macrophyllum | 3 | 1.11 (0.62 – 1.59) | 3 | 1.15 (0.65 – 1.65) | – | – | – | – | – | – | – | – |
| 2 | Stemonurus malaccensis | 4 | 1.36 (0.86 – 1.87) | 3 | 1.16 (0.65 – 1.66) | – | – | – | – | – | – | – | – |
| 3 | Stemonurus umbellatus | 5 | 1.98 (1.36 – 2.6) | 5 | 2.03 (1.39 – 2.67) | – | – | – | – | – | – | – | – |
| ILLICIACEAE | | | | | | | | | | | | | |
| 1 | Illicium sp. | – | – | – | – | – | – | – | – | 1 | 0.52 (0.52 – 0.52) | – | – |
| IRVINGIACEAE | | | | | | | | | | | | | |
| 1 | Irvingia malayana | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| JUGLANDACEAE | | | | | | | | | | | | | |
| 1 | Engelhardia serrata | – | – | – | – | 1 | 3.37 (3.37 – 3.37) | 1 | 4.04 (4.04 – 4.04) | – | – | – | – |
| LAURACEAE | | | | | | | | | | | | | |
| 1 | Actinodaphne glabra | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 2 | Alseodaphne oblanceolata | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 3 | Alseodaphne sp. | 2 | 2.25 (1.15 – 3.36) | 1 | 1.71 (1.71 – 1.71) | – | – | – | – | – | – | – | – |
| 4 | Beilschmiedia maingayi | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 5 | Beilschmiedia sp. | – | – | – | – | 1 | 1.34 (1.34 – 1.34) | 1 | 1.37 (1.37 – 1.37) | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| | LAURACEAE (Continued) | | | | | | | | | | | | |
| 6 | Cinnamomum angustitepalum | – | – | – | – | – | – | – | – | 2 | 1.21 (0.62 – 1.81) | 2 | 1.15 (0.59 – 1.72) |
| 7 | Cinnamomum burmannii | – | – | – | – | – | – | – | – | 1 | 0.52 (0.52 – 0.52) | 1 | 0.49 (0.49 – 0.49) |
| 8 | Cinnamomum sp. | – | – | – | – | – | – | – | – | 3 | 1.64 (0.93 – 2.36) | 3 | 1.56 (0.88 – 2.23) |
| 9 | Cryptocarya ferrea | 1 | 0.72 (0.72 – 0.72) | 1 | 0.71 (0.71 – 0.71) | 1 | 1.6 (1.6 – 1.6) | 1 | 1.63 (1.63 – 1.63) | – | – | – | – |
| 10 | Cryptocarya griffithiana var. crassinervia | 1 | 0.65 (0.65 – 0.65) | 1 | 0.66 (0.66 – 0.66) | – | – | – | – | – | – | – | – |
| 11 | Dehaasia caesia | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 12 | Dehaasia cuneata | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 13 | Dehaasia incrassata | 2 | 1.95 (1 – 2.91) | 2 | 1.9 (0.97 – 2.84) | – | – | – | – | – | – | – | – |
| 14 | Dehaasia sp. | 1 | 1.55 (1.55 – 1.55) | 1 | 1.78 (1.78 – 1.78) | 1 | 1.45 (1.45 – 1.45) | 1 | 1.65 (1.65 – 1.65) | – | – | – | – |
| 15 | Endiandra sp | – | – | – | – | 8 | 8.27 (6.49 – 10.04) | 7 | 8.05 (6.12 – 9.98) | – | – | – | – |
| 16 | Lindera kinabaluensis | – | – | – | – | – | – | – | – | 1 | 0.51 (0.51 – 0.51) | 2 | 0.95 (0.48 – 1.41) |
| 17 | Litsea accedens | 4 | 1.47 (0.93 – 2.01) | 4 | 1.53 (0.97 – 2.09) | – | – | – | – | – | – | – | – |
| 18 | Litsea cf.lancifolia | – | – | – | – | 1 | 1.91 (1.91 – 1.91) | 1 | 1.91 (1.91 – 1.91) | – | – | – | – |
| 19 | Litsea costalis | – | – | – | – | – | – | – | – | 7 | 3.28 (2.49 – 4.06) | 7 | 3.13 (2.38 – 3.88) |
| 20 | Litsea cubeba | 1 | 0.39 (0.39 – 0.39) | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | 3 | 1.6 (0.9 – 2.29) | 3 | 1.51 (0.85 – 2.16) |
| 21 | Litsea cylindrocarpa | – | – | – | – | – | – | – | – | 6 | 2.8 (2.04 – 3.56) | 7 | 3.12 (2.37 – 3.87) |
| 22 | Litsea fulva | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 23 | Litsea grandis | 1 | 1.55 (1.55 – 1.55) | 1 | 0.82 (0.82 – 0.82) | – | – | – | – | – | – | – | – |
| 24 | Litsea oppositifolia | – | – | – | – | 1 | 1.21 (1.21 – 1.21) | 1 | 1.23 (1.23 – 1.23) | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| LAURACEAE (Continued) | | | | | | | | | | | | | |
| 25 | Litsea sessilis | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 26 | Litsea sp. | 1 | 2.31 (2.31 – 2.31) | 1 | 2.39 (2.39 – 2.39) | – | – | – | – | 3 | 1.44 (0.81 – 2.07) | 3 | 1.37 (0.77 – 1.97) |
| 27 | Phoebe cf.grandis | – | – | – | – | 5 | 9.28 (6.37 – 12.18) | 5 | 6.69 (4.59 – 8.79) | – | – | – | – |
| LECYTHIDACEAE | | | | | | | | | | | | | |
| 1 | Barringtonia lanceolata | 6 | 2.22 (1.62 – 2.83) | 6 | 2.31 (1.68 – 2.93) | – | – | – | – | – | – | – | – |
| 2 | Planchonia obovata | 2 | 3.97 (2.03 – 5.92) | 2 | 3.75 (1.91 – 5.58) | – | – | – | – | – | – | – | – |
| LOGANIACEAE | | | | | | | | | | | | | |
| 1 | Fagraea cuspidata | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| LYTHRACEAE | | | | | | | | | | | | | |
| 1 | Duabanga moluccana | – | – | – | – | 1 | 11.25 (11.25 – 11.25) | 1 | 10.01 (10.01 – 10.01) | – | – | – | – |
| MAGNOLIACEAE | | | | | | | | | | | | | |
| 1 | Magnolia candollii | 2 | 0.57 (0.29 – 0.85) | 2 | 0.58 (0.3 – 0.86) | – | – | – | – | – | – | – | – |
| 2 | Magnolia carsonii | – | – | – | – | – | – | – | – | 7 | 3.83 (2.91 – 4.75) | 7 | 3.63 (2.76 – 4.5) |
| 3 | Magnolia gigantifolia | 2 | 0.84 (0.43 – 1.26) | 2 | 0.84 (0.43 – 1.25) | – | – | – | – | – | – | – | – |
| 4 | Magnolia sp. | 1 | 0.42 (0.42 – 0.42) | 1 | 0.45 (0.45 – 0.45) | – | – | – | – | 8 | 3.34 (2.62 – 4.05) | 8 | 3.16 (2.48 – 3.84) |
| MELASTOMATACEAE | | | | | | | | | | | | | |
| 1 | Melastoma sabahense | – | | – | – | – | – | – | – | 8 | 3.6 (2.83 – 4.37) | 10 | 4.35 (3.58 – 5.12) |
| 2 | Memecylon beccarianum | 1 | 0.4 (0.4 – 0.4) | 1 | 0.22 (0.22 – 0.22) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MELIACEAE | | | | | | | | | | | | | |
| 1 | Aglaia cf.leucophylla | – | | – | – | 12 | 19.85 (16.88 – 22.83) | 12 | 15.3 (13.01 – 17.59) | – | – | – | – |
| 2 | Aglaia elliptica | 1 | 0.66 (0.66 – 0.66) | 1 | 0.68 (0.68 – 0.68) | – | – | – | – | 3 | 1.64 (0.93 – 2.36) | 3 | 1.43 (0.81 – 2.05) |
| 3 | Aglaia elliptica subsp. clementis | 2 | 0.55 (0.28 – 0.82) | 2 | 0.36 (0.18 – 0.54) | 37 | 31.55 (29.92 – 33.17) | 35 | 31.37 (29.66 – 33.08) | – | – | – | – |
| 4 | Aglaia meliosmoides | 1 | 0.43 (0.43 – 0.43) | 1 | 0.44 (0.44 – 0.44) | – | – | – | – | – | – | – | – |
| 5 | Aglaia monozyga | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 6 | Aglaia odoratissima | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 7 | Aglaia rufinervis | 3 | 1.28 (0.72 – 1.84) | 3 | 1.31 (0.74 – 1.88) | – | – | – | – | – | – | – | – |
| 8 | Aglaia sp. | – | – | – | – | 1 | 1.2 (1.2 – 1.2) | 1 | 1.24 (1.24 – 1.24) | 3 | 1.53 (0.87 – 2.2) | 3 | 1.45 (0.82 – 2.08) |
| 9 | Aglaia tomentosa | 2 | 0.71 (0.36 – 1.06) | 2 | 0.74 (0.38 – 1.1) | – | – | – | – | – | – | – | – |
| 10 | Aphanamixis borneensis | 2 | 0.75 (0.38 – 1.11) | 2 | 0.8 (0.41 – 1.19) | – | – | – | – | – | – | – | – |
| 11 | Aphanamixis polystachya | – | – | – | – | 7 | 9.63 (7.32 – 11.94) | 7 | 11.36 (8.64 – 14.09) | – | – | – | – |
| 12 | Chisocheton beccarianus | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 13 | Chisocheton ceramicus | 1 | 0.36 (0.36 – 0.36) | 1 | 0.17 (0.17 – 0.17) | – | – | – | – | – | – | – | – |
| 14 | Chisocheton cf.medusae | – | – | – | – | 1 | 2.98 (2.98 – 2.98) | 1 | 2.78 (2.78 – 2.78) | – | – | – | – |
| 15 | Chisocheton lansiifolius | – | – | – | – | 1 | 1.62 (1.62 – 1.62) | 1 | 1.6 (1.6 – 1.6) | – | – | – | – |
| 16 | Chisocheton pentandrus subsp. paucijugus | 8 | 2.63 (2.07 – 3.19) | 8 | 2.67 (2.1 – 3.25) | – | – | – | – | – | – | – | – |
| 17 | Dysoxylum carolinae | 1 | 2.39 (2.39 – 2.39) | 1 | 2.24 (2.24 – 2.24) | – | – | – | – | – | – | – | – |
| 18 | Dysoxylum oppositifolium | 1 | 0.39 (0.39 – 0.39) | 1 | 0.41 (0.41 – 0.41) | – | – | – | – | – | – | – | – |

## Table 5. (Continued)

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MELIACEAE (Continued) | | | | | | | | | | | | | |
| 19 | Dysoxylum rugulosum | 2 | 1.12 (0.57 – 1.66) | 2 | 1.11 (0.57 – 1.66) | – | – | – | – | – | – | – | – |
| 20 | Dysoxylum sp. | – | – | – | – | 2 | 7.24 (3.69 – 10.79) | 2 | 8.64 (4.41 – 12.88) | – | – | – | – |
| 21 | Euonymus castaneifolius | – | – | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 22 | Lansium domesticum | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 23 | Reinwardtiodendron humile | 1 | 0.37 (0.37 – 0.37) | 1 | 0.18 (0.18 – 0.18) | – | – | – | – | – | – | – | – |
| 24 | Walsura pinnata | 3 | 1.14 (0.64 – 1.64) | 3 | 1.18 (0.66 – 1.69) | – | – | – | – | – | – | – | – |
| MORACEAE | | | | | | | | | | | | | |
| 1 | Artocarpus elasticus | 1 | 0.42 (0.42 – 0.42) | 1 | 0.43 (0.43 – 0.43) | 1 | 3.19 (3.19 – 3.19) | 1 | 3.72 (3.72 – 3.72) | – | – | – | – |
| 2 | Artocarpus kemando | 1 | 0.85 (0.85 – 0.85) | 1 | 0.85 (0.85 – 0.85) | – | – | – | – | – | – | – | – |
| 3 | Artocarpus lanceifolius | 10 | 3.8 (3.13 – 4.48) | 8 | 3.46 (2.72 – 4.2) | – | – | – | – | – | – | – | – |
| 4 | Artocarpus melinoxylus | 1 | 0.5 (0.5 – 0.5) | 1 | 0.42 (0.42 – 0.42) | – | – | – | – | – | – | – | – |
| 5 | Artocarpus odoratissimus | 3 | 1.66 (0.93 – 2.38) | 3 | 1.46 (0.82 – 2.1) | – | – | – | – | – | – | – | – |
| 6 | Artocarpus sp. | 2 | 0.86 (0.44 – 1.28) | 2 | 0.88 (0.45 – 1.32) | – | – | – | – | – | – | – | – |
| 7 | Artocarpus tamaran | 1 | 1.25 (1.25 – 1.25) | 1 | 1.25 (1.25 – 1.25) | – | – | – | – | – | – | – | – |
| 8 | Ficus androchaete | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 9 | Ficus benjamina | – | – | – | – | 1 | 1.21 (1.21 – 1.21) | 1 | 1.12 (1.12 – 1.12) | – | – | – | – |
| 10 | Ficus deltoidea | – | – | – | – | – | – | – | – | 1 | 0.5 (0.5 – 0.5) | 1 | 0.47 (0.47 – 0.47) |
| 11 | Ficus fistulosa | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 12 | Ficus uniglandulosa | 1 | 0.5 (0.5 – 0.5) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| MYRISTICACEAE | | | | | | | | | | | | | |
| 1 | Gymnacranthera farquhariana var. zippeliana | 6 | 3.41 (2.48 – 4.33) | 6 | 3.51 (2.56 – 4.47) | – | – | – | – | – | – | – | – |
| 2 | Horsfieldia sp. | – | | – | – | 1 | 1.12 (1.12 – 1.12) | 1 | 1.15 (1.15 – 1.15) | – | – | – | – |
| 3 | Knema conferta | 5 | 1.47 (1.01 – 1.93) | 5 | 1.51 (1.04 – 1.98) | – | – | – | – | – | – | – | – |
| 4 | Knema galeata | 1 | 0.41 (0.41 – 0.41) | 1 | 0.42 (0.42 – 0.42) | – | – | – | – | – | – | – | – |
| 5 | Knema kunstleri | 5 | 1.67 (1.15 – 2.19) | 4 | 1.38 (0.87 – 1.88) | – | – | – | – | – | – | – | – |
| 6 | Knema kunstleri subsp alpinia | 4 | 1.52 (0.96 – 2.07) | 4 | 1.59 (1.01 – 2.17) | – | – | – | – | – | – | – | – |
| 7 | Knema laurina | 10 | 3.02 (2.49 – 3.56) | 11 | 3.06 (2.56 – 3.55) | – | – | – | – | – | – | – | – |
| 8 | Myristica maxima | 2 | 1.4 (0.72 – 2.09) | 2 | 1.93 (0.98 – 2.88) | – | – | – | – | – | – | – | – |
| MORACEAE | | | | | | | | | | | | | |
| 1 | Artocarpus elasticus | 1 | 0.42 (0.42 – 0.42) | 1 | 0.43 (0.43 – 0.43) | 1 | 3.19 (3.19 – 3.19) | 1 | 3.72 (3.72 – 3.72) | – | – | – | – |
| 2 | Artocarpus kemando | 1 | 0.85 (0.85 – 0.85) | 1 | 0.85 (0.85 – 0.85) | – | – | – | – | – | – | – | – |
| 3 | Artocarpus lanceifolius | 10 | 3.8 (3.13 – 4.48) | 8 | 3.46 (2.72 – 4.2) | – | – | – | – | – | – | – | – |
| 4 | Artocarpus melinoxylus | 1 | 0.5 (0.5 – 0.5) | 1 | 0.42 (0.42 – 0.42) | – | – | – | – | – | – | – | – |
| 5 | Artocarpus odoratissimus | 3 | 1.66 (0.93 – 2.38) | 3 | 1.46 (0.82 – 2.1) | – | – | – | – | – | – | – | – |
| 6 | Artocarpus sp. | 2 | 0.86 (0.44 – 1.28) | 2 | 0.88 (0.45 – 1.32) | – | – | – | – | – | – | – | – |
| 7 | Artocarpus tamaran | 1 | 1.25 (1.25 – 1.25) | 1 | 1.25 (1.25 – 1.25) | – | – | – | – | – | – | – | – |
| 8 | Ficus androchaete | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 9 | Ficus benjamina | – | – | – | – | 1 | 1.21 (1.21 – 1.21) | 1 | 1.12 (1.12 – 1.12) | – | – | – | – |
| 10 | Ficus deltoidea | – | – | – | – | – | – | – | – | 1 | 0.5 (0.5 – 0.5) | 1 | 0.47 (0.47 – 0.47) |

**Table 5. (Continued**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| MORACEAE (Continued) | | | | | | | | | | | | | |
| 11 | Ficus fistulosa | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 12 | Ficus uniglandulosa | 1 | 0.5 (0.5 – 0.5) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |
| MYRISTICACEAE | | | | | | | | | | | | | |
| 1 | Gymnacranthera farquhariana var. zippeliana | 6 | 3.41 (2.48 – 4.33) | 6 | 3.51 (2.56 – 4.47) | – | – | – | – | – | – | – | – |
| 2 | Horsfieldia sp. | – | | – | – | 1 | 1.12 (1.12 – 1.12) | 1 | 1.15 (1.15 – 1.15) | – | – | – | – |
| 3 | Knema conferta | 5 | 1.47 (1.01 – 1.93) | 5 | 1.51 (1.04 – 1.98) | – | – | – | – | – | – | – | – |
| 4 | Knema galeata | 1 | 0.41 (0.41 – 0.41) | 1 | 0.42 (0.42 – 0.42) | – | – | – | – | – | – | – | – |
| 5 | Knema kunstleri | 5 | 1.67 (1.15 – 2.19) | 4 | 1.38 (0.87 – 1.88) | – | – | – | – | – | – | – | – |
| 6 | Knema kunstleri subsp alpinia | 4 | 1.52 (0.96 – 2.07) | 4 | 1.59 (1.01 – 2.17) | – | – | – | – | – | – | – | – |
| 7 | Knema laurina | 10 | 3.02 (2.49 – 3.56) | 11 | 3.06 (2.56 – 3.55) | – | – | – | – | – | – | – | – |
| 8 | Myristica maxima | 2 | 1.4 (0.72 – 2.09) | 2 | 1.93 (0.98 – 2.88) | – | – | – | – | – | – | – | – |
| MYRISTICACEAE | | | | | | | | | | | | | |
| 1 | Ardisia colorata | 2 | 0.72 (0.37 – 1.07) | 2 | 0.55 (0.28 – 0.82) | – | – | – | – | – | – | – | – |
| 2 | Ardisia macrophylla | 1 | 0.37 (0.37 – 0.37) | 1 | 0.18 (0.18 – 0.18) | – | – | – | – | – | – | – | – |
| 3 | Myrsine sp. | – | – | – | – | – | – | – | – | 11 | 6.03 (5.06 – 7.01) | 11 | 5.94 (4.97 – 6.9) |
| MYRTACEAE | | | | | | | | | | | | | |
| 1 | Leptospermum flavescens | – | – | – | – | – | – | – | – | 8 | 7.84 (6.16 – 9.53) | 8 | 7.5 (5.89 – 9.11) |
| 2 | Leptospermum javanicum | – | – | – | – | – | – | – | – | 2 | 3.76 (1.92 – 5.6) | 2 | 3.68 (1.88 – 5.49) |
| 3 | Syzygium acuminatissima | – | – | – | – | – | – | – | – | 1 | 0.54 (0.54 – 0.54) | 1 | 0.51 (0.51 – 0.51) |

**Table 5. (Continued**

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MYRTACEAE (Continued) | | | | | | | | | | | | | |
| 5 | Syzygium barringtonioides | 3 | 1.63 (0.92 – 2.34) | 3 | 1.63 (0.92 – 2.35) | – | – | – | – | – | – | – | – |
| 6 | Syzygium caudatilimbum | 11 | 3.91 (3.28 – 4.55) | 11 | 3.56 (2.98 – 4.14) | – | – | – | – | – | – | – | – |
| 7 | Syzygium chrysanthum | 1 | 0.59 (0.59 – 0.59) | 1 | 0.62 (0.62 – 0.62) | – | – | – | – | – | – | – | – |
| 8 | Syzygium creaghii | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | 2 | 3.24 (1.65 – 4.83) | 2 | 3.22 (1.64 – 4.8) | – | – | – | – |
| 9 | Syzygium elopurae | 8 | 1.97 (1.55 – 2.39) | 8 | 1.61 (1.26 – 1.95) | – | – | – | – | – | – | – | – |
| 10 | Syzygium fastigiatum | 1 | 0.55 (0.55 – 0.55) | 1 | 0.56 (0.56 – 0.56) | 1 | 1.56 (1.56 – 1.56) | 1 | 1.56 (1.56 – 1.56) | – | – | – | – |
| 11 | Syzygium hirtum | – | – | – | – | 2 | 1.56 (0.8 – 2.33) | 2 | 1.59 (0.81 – 2.36) | 1 | 0.81 (0.81 – 0.81) | 1 | 0.78 (0.78 – 0.78) |
| 12 | Syzygium incarnata | – | – | – | – | – | – | – | – | 2 | 0.72 (0.37 – 1.08) | 6 | 2.27 (1.65 – 2.89) |
| 13 | Syzygium javanica | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 14 | Syzygium korthalsiana | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | 50 | 18.47 (17.76 – 19.18) | 53 | 18.15 (17.49 – 18.8) |
| 15 | Syzygium lineata | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 16 | Syzygium myrianthus | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 17 | Syzygium napiformis | 11 | 4.07 (3.41 – 4.73) | 11 | 4.2 (3.52 – 4.88) | – | – | – | – | – | – | – | – |
| 18 | Syzygium nitida | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 19 | Syzygium ochneocarpum | 1 | 0.93 (0.93 – 0.93) | 1 | 1.17 (1.17 – 1.17) | – | – | – | – | – | – | – | – |
| 20 | Syzygium palembanicum | 2 | 1.55 (0.79 – 2.31) | 2 | 1.6 (0.82 – 2.39) | – | – | – | – | – | – | – | – |
| 21 | Syzygium paraensis | – | – | – | – | – | – | – | – | 1 | 0.52 (0.52 – 0.52) | 1 | 0.49 (0.49 – 0.49) |
| 22 | Syzygium penibukanense | 1 | 0.37 (0.37 – 0.37) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MYRTACEAE (Continued) | | | | | | | | | | | | | |
| 23 | Syzygium punctilimba | – | – | – | – | – | – | – | – | 1 | 0.64 (0.64 – 0.64) | 1 | 0.61 (0.61 – 0.61) |
| 24 | Syzygium sandakanensis | 1 | 0.54 (0.54 – 0.54) | 1 | 0.57 (0.57 – 0.57) | 4 | 5.81 (3.67 – 7.94) | 4 | 5.87 (3.71 – 8.02) | – | – | – | – |
| 25 | Syzygium sp. | 1 | 0.4 (0.4 – 0.4) | 1 | 0.41 (0.41 – 0.41) | 1 | 1.14 (1.14 – 1.14) | 1 | 1.18 (1.18 – 1.18) | 7 | 3.64 (2.76 – 4.51) | 9 | 4.39 (3.54 – 5.24) |
| 26 | Syzygium villamilii | 2 | 0.76 (0.39 – 1.14) | 2 | 0.79 (0.4 – 1.18) | – | – | – | – | – | – | – | – |
| 27 | Tristaniopsis beccarii | – | – | – | – | – | – | – | – | – | – | 1 | 0.47 (0.47 – 0.47) |
| 28 | Tristaniopsis cf.obovata | – | – | – | – | – | – | – | – | 72 | 43.12 (41.96 – 44.28) | 74 | 42.59 (41.48 – 43.7) |
| 29 | Tristaniopsis elliptica | – | – | – | – | – | – | – | – | – | – | 5 | 2.06 (1.42 – 2.71) |
| 30 | Tristaniopsis sp. | – | – | – | – | – | – | – | – | 1 | 0.62 (0.62 – 0.62) | 1 | 0.59 (0.59 – 0.59) |
| OLACACEAE | | | | | | | | | | | | | |
| 1 | Ochanostachys amentacea | 3 | 1.25 (0.71 – 1.8) | 3 | 0.9 (0.51 – 1.29) | – | – | – | – | – | – | – | – |
| OLEACEAE | | | | | | | | | | | | | |
| 1 | Chionanthus callophyllus | 1 | 0.46 (0.46 – 0.46) | 1 | 0.47 (0.47 – 0.47) | – | – | – | – | – | – | – | – |
| 2 | Chionanthus curvicarpus | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 3 | Chionanthus pluriflorus | – | | – | – | 5 | 9.92 (6.81 – 13.03) | 5 | 9.05 (6.21 – 11.88) | 1 | 0.5 (0.5 – 0.5) | 1 | 0.47 (0.47 – 0.47) |
| 4 | Chionanthus pubicalyx | 2 | 0.76 (0.39 – 1.13) | 2 | 0.78 (0.4 – 1.17) | – | – | – | – | – | – | – | – |
| 5 | Chionanthus spicatus | – | | – | – | 5 | 4.67 (3.21 – 6.14) | 5 | 4.78 (3.28 – 6.27) | – | – | – | – |
| PHYLLOCLADACEAE | | | | | | | | | | | | | |
| 1 | Phyllocladus hypophyllus | – | | – | – | – | – | – | – | – | – | 2 | 0.94 (0.48 – 1.4) |
| PITTOSPORACEAE | | | | | | | | | | | | | |
| 1 | Pittosporum ferrugineum | – | | – | – | – | – | – | – | 1 | 0.61 (0.61 – 0.61) | 1 | 0.58 (0.58 – 0.58) |

**Table 5. (Continued**

| Family/Species | | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| PODOCARPACEAE | | | | | | | | | | | | | |
| 1 | Dacrycarpus imbricatus | – | | – | – | – | – | – | – | 2 | 1.03 (0.53 – 1.54) | 2 | 0.97 (0.5 – 1.45) |
| 2 | Dacrydium xanthandrum | – | | – | – | – | – | – | – | 7 | 15.43 (11.73 – 19.14) | 7 | 13.82 (10.5 – 17.13) |
| 3 | Falcatifolium falciforme | – | | – | – | – | – | – | – | 59 | 23.33 (22.56 – 24.09) | 63 | 23.19 (22.48 – 23.9) |
| 4 | Phyllocladus hypophyllus | – | | – | – | – | – | – | – | 46 | 23.17 (22.21 – 24.14) | 45 | 22.5 (21.54 – 23.46) |
| POLYGALACEAE | | | | | | | | | | | | | |
| 1 | Suregada glomerulata | – | | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | – | – | – | – |
| 2 | Xanthophyllum flavescens | 4 | 2.35 (1.49 – 3.22) | 4 | 2.35 (1.49 – 3.21) | 1 | 1.13 (1.13 – 1.13) | – | – | – | – | – | – |
| 3 | Xanthophyllum montanum | 15 | 5.83 (5.12 – 6.55) | 15 | 5.75 (5.05 – 6.45) | – | – | – | – | – | – | – | – |
| 4 | Xanthophyllum rufum | 4 | 1.52 (0.96 – 2.07) | 4 | 1.56 (0.99 – 2.14) | – | – | – | – | – | – | – | – |
| 5 | Xanthophyllum sp. | – | | 2 | 0.74 (0.38 – 1.1) | – | – | – | – | – | – | – | – |
| PROTEACEAE | | | | | | | | | | | | | |
| 1 | Helicia petiolaris | 6 | 3.68 (2.68 – 4.68) | 5 | 3.27 (2.25 – 4.3) | – | – | – | – | – | – | – | – |
| 2 | Heliciopsis velutina | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| RHAMNACEAE | | | | | | | | | | | | | |
| 1 | Ziziphus angustifolius | 2 | 0.97 (0.5 – 1.45) | 2 | 0.99 (0.5 – 1.47) | – | – | – | – | – | – | – | – |
| RHIZOPHORACEAE | | | | | | | | | | | | | |
| 1 | Carallia brachiata | 3 | 1.08 (0.61 – 1.54) | 2 | 0.87 (0.44 – 1.3) | – | – | – | – | – | – | – | – |
| ROSACEAE | | | | | | | | | | | | | |
| 1 | Prunus arborea | – | | – | – | – | – | – | – | 6 | 2.8 (2.04 – 3.56) | 8 | 3.3 (2.59 – 4.01) |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| RUBIACEAE | | | | | | | | | | | | | |
| 1 | Aidia borneensis | 1 | 0.36 (0.36 – 0.36) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 2 | Canthium confertum | – | | – | – | – | – | – | – | 2 | 0.8 (0.41 – 1.2) | 2 | 0.76 (0.39 – 1.14) |
| 3 | Diplospora malaccense | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 4 | Diplospora singularis | 7 | 2.57 (1.95 – 3.18) | 7 | 2.63 (2 – 3.26) | – | – | – | – | – | – | – | – |
| 5 | Diplospora sp. | 1 | 0.44 (0.44 – 0.44) | – | – | – | – | – | – | – | – | – | – |
| 6 | Ixora brachyantha | 2 | 0.72 (0.36 – 1.07) | 2 | 0.74 (0.38 – 1.1) | – | – | – | – | – | – | – | – |
| 7 | Ixora sp. | 2 | 0.74 (0.38 – 1.1) | 2 | 0.78 (0.4 – 1.17) | – | – | – | – | – | – | – | – |
| 8 | Mussaendopsis beccariana | 1 | 1.55 (1.55 – 1.55) | 1 | 1.46 (1.46 – 1.46) | – | – | – | – | – | – | – | – |
| 9 | Neonauclea artocarpoides | – | | – | – | 2 | 3.91 (2 – 5.83) | 2 | 3.82 (1.95 – 5.69) | – | – | – | – |
| 10 | Neonauclea gigantea | 1 | 0.44 (0.44 – 0.44) | 1 | 0.45 (0.45 – 0.45) | – | – | – | – | – | – | – | – |
| 11 | Porterandia chanii | 1 | 0.36 (0.36 – 0.36) | 1 | 0.17 (0.17 – 0.17) | – | – | – | – | – | – | – | – |
| 12 | Praravinia suberosa | 2 | 0.53 (0.27 – 0.79) | 2 | 0.54 (0.28 – 0.81) | – | – | – | – | – | – | – | – |
| 13 | Rothmannia pseudoternifolia var. pseudoternifolia | 2 | 0.83 (0.42 – 1.24) | 2 | 0.85 (0.43 – 1.26) | – | – | – | – | – | – | – | – |
| 14 | Urophyllum congestiflorum | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 15 | Urophyllum streptopodium | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| RUTACEAE | | | | | | | | | | | | | |
| 1 | Acronychia pedunculata | – | | – | – | – | – | – | – | 2 | 1.02 (0.52 – 1.52) | 2 | 0.96 (0.49 – 1.43) |
| 2 | Maclurodendron porteri | – | | – | – | – | – | – | – | 12 | 6.7 (5.7 – 7.7) | 12 | 6.44 (5.48 – 7.41) |
| 3 | Maclurodendron sp. | – | | – | – | – | – | – | – | 4 | 1.72 (1.09 – 2.36) | 4 | 1.63 (1.03 – 2.22) |

**Table 5. (Continued)**

| Family/Species | | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RUTACEAE (Continued) | | | | | | | | | | | | | |
| 4 | Melicope sp. | – | | – | – | – | – | – | – | 5 | 2.28 (1.56 – 2.99) | 7 | 3.1 (2.36 – 3.85) |
| SAPINDACEAE | | | | | | | | | | | | | |
| 1 | Dimocarpus longan | 1 | 0.78 (0.78 – 0.78) | 1 | 0.78 (0.78 – 0.78) | – | – | – | – | – | – | – | – |
| 2 | Lepisanthes amoena | 1 | 0.36 (0.36 – 0.36) | 1 | 0.17 (0.17 – 0.17) | – | – | – | – | – | – | – | – |
| 3 | Nephelium cuspidatum | 9 | 3.69 (2.97 – 4.4) | 9 | 3.57 (2.88 – 4.26) | – | – | – | – | – | – | – | – |
| 4 | Nephelium lappaceum | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 5 | Nephelium ramboutan-ake | 3 | 2.09 (1.18 – 3) | 3 | 2.09 (1.18 – 3) | – | – | – | – | – | – | – | – |
| 6 | Pometia pinnata | 2 | 1.06 (0.54 – 1.59) | 2 | 1.06 (0.54 – 1.58) | – | – | – | – | – | – | – | – |
| 7 | Pometia ridleyi | – | | – | – | 1 | 7.44 (7.44 – 7.44) | 1 | 6.25 (6.25 – 6.25) | – | – | – | – |
| 8 | Xerospermum noronhianum | 5 | 1.83 (1.26 – 2.4) | 5 | 1.89 (1.29 – 2.48) | – | – | – | – | – | – | – | – |
| 9 | Xerospermum sp. | 2 | 1.8 (0.92 – 2.68) | 2 | 1.62 (0.82 – 2.41) | – | – | – | – | – | – | – | – |
| SAPOTACEAE | | | | | | | | | | | | | |
| 1 | Madhuca endertii | – | | – | – | – | – | – | – | 2 | 1.04 (0.53 – 1.55) | 2 | 0.98 (0.5 – 1.47) |
| 2 | Palaquium dasyphyllum | 3 | 4.88 (2.75 – 7) | 4 | 4.93 (3.12 – 6.75) | – | – | – | – | – | – | – | – |
| 3 | Palaquium endenii | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 4 | Palaquium endertii | 2 | 0.77 (0.39 – 1.14) | 2 | 0.79 (0.4 – 1.17) | – | – | – | – | – | – | – | – |
| 5 | Palaquium ferrugineum | – | | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 6 | Palaquium glabrescens | 4 | 2.02 (1.27 – 2.76) | 4 | 1.95 (1.23 – 2.66) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I | Upper Montane Forest 2005 n | Upper Montane Forest 2005 I.V.I | Upper Montane Forest 2009 n | Upper Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAPOTACEAE (Continued) | | | | | | | | | | | | | |
| 7 | Palaquium rostratum | 2 | 0.8 (0.41 – 1.19) | 2 | 0.83 (0.42 – 1.23) | – | – | – | – | – | – | – | – |
| 8 | Palaquium sericeum | 1 | 0.38 (0.38 – 0.38) | 1 | 0.39 (0.39 – 0.39) | – | – | – | – | – | – | – | – |
| 9 | Palaquium sp. | – | | – | – | – | – | – | – | 3 | 1.25 (0.7 – 1.79) | 3 | 1.18 (0.67 – 1.69) |
| 10 | Palaquium stenophyllum | 2 | 0.77 (0.39 – 1.14) | 2 | 0.79 (0.4 – 1.18) | – | – | – | – | – | – | – | – |
| SAXIFRAGACEAE | | | | | | | | | | | | | |
| 1 | Polyosma sp. | – | | – | – | – | – | – | – | – | – | 6 | 2.95 (2.15 – 3.75) |
| 2 | Weinmannia blumei | – | | – | – | – | – | – | – | – | – | 1 | 0.52 (0.52 – 0.52) |
| SCYPHOSTEGIACEAE | | | | | | | | | | | | | |
| 1 | Scyphostegia borneensis | – | | – | – | 2 | 1.62 (0.83 – 2.41) | 2 | 1.63 (0.83 – 2.43) | – | – | – | – |
| STERCULIACEAE | | | | | | | | | | | | | |
| 1 | Heritiera elata | 1 | 0.4 (0.4 – 0.4) | 1 | 0.41 (0.41 – 0.41) | – | – | – | – | – | – | – | – |
| 2 | Heritiera javanica | 2 | 0.82 (0.42 – 1.22) | 2 | 0.63 (0.32 – 0.94) | – | – | – | – | – | – | – | – |
| 3 | Leptonychia heteroclita | 1 | 0.36 (0.36 – 0.36) | 1 | 0.17 (0.17 – 0.17) | – | – | – | – | – | – | – | – |
| 4 | Pterospermum elongatum | – | | – | – | 26 | 32.58 (30.22 – 34.94) | 26 | 37.52 (34.8 – 40.24) | – | – | – | – |
| 5 | Scaphium discolor | 1 | 1.36 (1.36 – 1.36) | 1 | 1.35 (1.35 – 1.35) | – | – | – | – | – | – | – | – |
| 6 | Scaphium longipetiolatum | 2 | 1.94 (0.99 – 2.89) | 3 | 2.54 (1.44 – 3.65) | – | – | – | – | – | – | – | – |
| 7 | Sterculia coccinea | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| 8 | Sterculia cordata | 2 | 1.5 (0.76 – 2.23) | 2 | 1.47 (0.75 – 2.19) | – | – | – | – | – | – | – | – |
| 9 | Sterculia rubiginosa | – | | – | – | 1 | 1.1 (1.1 – 1.1) | 1 | 1.91 (1.91 – 1.91) | – | – | – | – |

## Table 5. (Continued)

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| STERCULIACEAE (Continued) | | | | | | | | | | | | | |
| 10 | Sterculia sp. | 1 | 0.43 (0.43 – 0.43) | 1 | 0.44 (0.44 – 0.44) | – | – | – | – | – | – | – | – |
| 11 | Sterculia stipulata | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| SYMPLOCACEAE | | | | | | | | | | | | | |
| 1 | Symplocos celastrifolia | – | – | – | – | – | – | – | – | 2 | 1.03 (0.53 – 1.54) | 2 | 0.97 (0.5 – 1.45) |
| THEACEAE | | | | | | | | | | | | | |
| 1 | Adinandra acuminata | – | – | – | – | – | – | – | – | 1 | 1.18 (1.18 – 1.18) | 1 | 1.15 (1.15 – 1.15) |
| 2 | Adinandra clemensiae | – | – | – | – | – | – | – | – | 1 | 0.54 (0.54 – 0.54) | 1 | 0.51 (0.51 – 0.51) |
| 3 | Adinandra sp. | – | – | – | – | – | – | – | – | 2 | 1.25 (0.64 – 1.87) | 2 | 1.23 (0.63 – 1.84) |
| 4 | Gordonia sp. | – | – | – | – | – | – | – | – | 1 | 0.53 (0.53 – 0.53) | 2 | 0.96 (0.49 – 1.44) |
| 5 | Schima wallichii | 1 | 1.77 (1.77 – 1.77) | 1 | 1.73 (1.73 – 1.73) | – | – | – | – | – | – | – | – |
| 6 | Ternstroemia aneura | – | – | – | – | – | – | – | – | 3 | 1.87 (1.05 – 2.68) | 4 | 2.24 (1.42 – 3.07) |
| 7 | Ternstroemia beccarii | – | – | – | – | – | – | – | – | 34 | 14.33 (13.52 – 15.13) | 35 | 13.82 (13.06 – 14.57) |
| 8 | Ternstroemia patens | 1 | 0.42 (0.42 – 0.42) | 1 | 0.43 (0.43 – 0.43) | – | – | – | – | – | – | – | – |
| 9 | Ternstroemia sp. | – | | – | – | – | – | – | – | 25 | 11.08 (10.24 – 11.91) | 27 | 11.56 (10.75 – 12.37) |
| TILIACEAE | | | | | | | | | | | | | |
| 11 | Ficus fistulosa | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 12 | Ficus uniglandulosa | 1 | 0.5 (0.5 – 0.5) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |
| 11 | Ficus fistulosa | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 12 | Ficus uniglandulosa | 1 | 0.5 (0.5 – 0.5) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |

## Table 5. (Continued)

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| STERCULIACEAE (Continued) | | | | | | | | | | | | | |
| 10 | Sterculia sp. | 1 | 0.43 (0.43 – 0.43) | 1 | 0.44 (0.44 – 0.44) | – | – | – | – | – | – | – | – |
| 11 | Sterculia stipulata | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| SYMPLOCACEAE | | | | | | | | | | | | | |
| 1 | Symplocos celastrifolia | – | – | – | – | – | – | – | – | 2 | 1.03 (0.53 – 1.54) | 2 | 0.97 (0.5 – 1.45) |
| THEACEAE | | | | | | | | | | | | | |
| 1 | Adinandra acuminata | – | – | – | – | – | – | – | – | 1 | 1.18 (1.18 – 1.18) | 1 | 1.15 (1.15 – 1.15) |
| 2 | Adinandra clemensiae | – | – | – | – | – | – | – | – | 1 | 0.54 (0.54 – 0.54) | 1 | 0.51 (0.51 – 0.51) |
| 3 | Adinandra sp. | – | – | – | – | – | – | – | – | 2 | 1.25 (0.64 – 1.87) | 2 | 1.23 (0.63 – 1.84) |
| 4 | Gordonia sp. | – | – | – | – | – | – | – | – | 1 | 0.53 (0.53 – 0.53) | 2 | 0.96 (0.49 – 1.44) |
| 5 | Schima wallichii | 1 | 1.77 (1.77 – 1.77) | 1 | 1.73 (1.73 – 1.73) | – | – | – | – | – | – | – | – |
| 6 | Ternstroemia aneura | – | – | – | – | – | – | – | – | 3 | 1.87 (1.05 – 2.68) | 4 | 2.24 (1.42 – 3.07) |
| 7 | Ternstroemia beccarii | – | – | – | – | – | – | – | – | 34 | 14.33 (13.52 – 15.13) | 35 | 13.82 (13.06 – 14.57) |
| 8 | Ternstroemia patens | 1 | 0.42 (0.42 – 0.42) | 1 | 0.43 (0.43 – 0.43) | – | – | – | – | – | – | – | – |
| 9 | Ternstroemia sp. | – | | – | – | – | – | – | – | 25 | 11.08 (10.24 – 11.91) | 27 | 11.56 (10.75 – 12.37) |
| TILIACEAE | | | | | | | | | | | | | |
| 11 | Ficus fistulosa | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 12 | Ficus uniglandulosa | 1 | 0.5 (0.5 – 0.5) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |
| 11 | Ficus fistulosa | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| 12 | Ficus uniglandulosa | 1 | 0.5 (0.5 – 0.5) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| Family/Species | | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| STERCULIACEAE (Continued) | | | | | | | | | | | | | |
| 10 | Sterculia sp. | 1 | 0.43 (0.43 – 0.43) | 1 | 0.44 (0.44 – 0.44) | – | – | – | – | – | – | – | – |
| 11 | Sterculia stipulata | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| SYMPLOCACEAE | | | | | | | | | | | | | |
| 1 | Symplocos celastrifolia | – | – | – | – | – | – | – | – | 2 | 1.03 (0.53 – 1.54) | 2 | 0.97 (0.5 – 1.45) |
| THEACEAE | | | | | | | | | | | | | |
| 1 | Adinandra acuminata | – | – | – | – | – | – | – | – | 1 | 1.18 (1.18 – 1.18) | 1 | 1.15 (1.15 – 1.15) |
| 2 | Adinandra clemensiae | – | – | – | – | – | – | – | – | 1 | 0.54 (0.54 – 0.54) | 1 | 0.51 (0.51 – 0.51) |
| 3 | Adinandra sp. | – | – | – | – | – | – | – | – | 2 | 1.25 (0.64 – 1.87) | 2 | 1.23 (0.63 – 1.84) |
| 4 | Gordonia sp. | – | – | – | – | – | – | – | – | 1 | 0.53 (0.53 – 0.53) | 2 | 0.96 (0.49 – 1.44) |
| 5 | Schima wallichii | 1 | 1.77 (1.77 – 1.77) | 1 | 1.73 (1.73 – 1.73) | – | – | – | – | – | – | – | – |
| 6 | Ternstroemia aneura | – | – | – | – | – | – | – | – | 3 | 1.87 (1.05 – 2.68) | 4 | 2.24 (1.42 – 3.07) |
| 7 | Ternstroemia beccarii | – | – | – | – | – | – | – | – | 34 | 14.33 (13.52 – 15.13) | 35 | 13.82 (13.06 – 14.57) |
| 8 | Ternstroemia patens | 1 | 0.42 (0.42 – 0.42) | 1 | 0.43 (0.43 – 0.43) | – | – | – | – | – | – | – | – |
| 9 | Ternstroemia sp. | – | | – | – | – | – | – | – | 25 | 11.08 (10.24 – 11.91) | 27 | 11.56 (10.75 – 12.37) |
| TILIACEAE | | | | | | | | | | | | | |
| 1 | Jarandersonia sp. | 1 | 0.39 (0.39 – 0.39) | 1 | 0.41 (0.41 – 0.41) | – | – | – | – | – | – | – | – |
| 2 | Microcos antidesmifolia | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 3 | Microcos crassifolia | 1 | 0.42 (0.42 – 0.42) | 1 | 0.23 (0.23 – 0.23) | – | – | – | – | – | – | – | – |
| 4 | Microcos elmeri | 1 | 0.51 (0.51 – 0.51) | 1 | 1.41 (1.41 – 1.41) | – | – | – | – | – | – | – | – |

**Table 5. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | | Upper Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| TILIACEAE (Continued) | | | | | | | | | | | | | |
| 5 | Microcos latistipulata | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| 6 | Microcos triflora var. longipetiolata | – | | – | – | 4 | 4.58 (2.89 – 6.26) | 4 | 1.86 (1.18 – 2.55) | – | – | – | – |
| 7 | Pentace laxiflora | 1 | 0.36 (0.36 – 0.36) | 1 | 0.37 (0.37 – 0.37) | – | – | – | – | – | – | – | – |
| ULMACEAE | | | | | | | | | | | | | |
| 1 | Celtis sp. | 1 | 0.4 (0.4 – 0.4) | 1 | 0.41 (0.41 – 0.41) | – | – | – | – | – | – | – | – |
| 2 | Celtis timorensis | – | | – | – | 3 | 3.69 (2.08 – 5.3) | 3 | 3.75 (2.12 – 5.39) | – | – | – | – |
| 3 | Gironniera parvifolia | 1 | 0.36 (0.36 – 0.36) | – | – | – | – | – | – | – | – | – | – |
| URTICACEAE | | | | | | | | | | | | | |
| 1 | Dendrocnide sp. | – | – | – | – | 3 | 2.87 (1.62 – 4.13) | 3 | 2.96 (1.67 – 4.25) | – | – | – | – |
| 2 | Oreocnide trinervis | – | – | – | – | 1 | 1.34 (1.34 – 1.34) | 1 | 1.34 (1 .34 – 1.34) | – | – | – | – |
| VERBENACEAE | | | | | | | | | | | | | |
| 1 | Teijsmanniodendron bogoriense | 1 | 0.39 (0.39 – 0.39) | 1 | 0.4 (0.4 – 0.4) | – | – | – | – | – | – | – | – |
| 2 | Teijsmanniodendron glabrum | 2 | 0.76 (0.39 – 1.13) | 2 | 0.78 (0.4 – 1.16) | – | – | – | – | – | – | – | – |
| 3 | Teijsmanniodendron simplicifolium | 1 | 0.37 (0.37 – 0.37) | 1 | 0.38 (0.38 – 0.38) | – | – | – | – | – | – | – | – |
| WINTERACEAE | | | | | | | | | | | | | |
| 1 | Tasmannia piperita | – | – | – | – | – | – | – | – | 5 | | 4 | 1.84 (1.16 – 2.51) |
| 12 | Ficus uniglandulosa | 1 | 0.5 (0.5 – 0.5) | 1 | 0.5 (0.5 – 0.5) | – | – | – | – | – | – | – | – |

**Table 6.** List of species with number of stem (n) and important value index (I.V.I) along the altitudinal zone in selectively logged forest.

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| ALANGIACEAE | | | | | | | | | |
| 1 | Alangium javanicum | 1 | 0.77 (0.77 – 0.77) | 1 | 0.69 (0.69 – 0.69) | _ | – | – | – |
| 2 | Alangium sp. | – | – | – | – | 1 | 1.4 (1.4 – 1.4) | 1 | 1.3 (1.3 – 1.3) |
| ANACARDIACEAE | | | | | | | | | |
| 1 | Melanochyla beccariana | 1 | 0.79 (0.79 – 0.79) | 1 | 0.71 (0.71 – 0.71) | _ | – | – | – |
| 2 | Melanochyla elmeri | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.07 (1.07 – 1.07) |
| 3 | Semecarpus sp. | 1 | 0.84 (0.84 – 0.84) | 1 | 0.73 (0.73 – 0.73) | _ | – | – | – |
| ANNONACEAE | | | | | | | | | |
| 1 | Goniothalamus fasciculatus | – | – | – | – | 4 | 4.56 (2.89 – 6.24) | 5 | 6.05 (4.15 – 7.94) |
| 2 | Neouvaria accuminatissima | 1 | 0.85 (0.85 – 0.85) | 1 | 0.74 (0.74 – 0.74) | _ | – | – | – |
| 3 | Neouvaria sp. | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | – | – |
| 4 | Orophea sp. | 1 | 0.98 (0.98 – 0.98) | 1 | 0.84 (0.84 – 0.84) | _ | – | – | – |
| 5 | Polyalthia obliqua | – | – | 3 | 1.28 (0.72 – 1.84) | _ | – | – | – |
| 6 | Xylopia ferruginea | 1 | 1.48 (1.48 – 1.48) | 2 | 1.26 (0.64 – 1.88) | _ | – | – | – |
| APOCYNACEAE | | | | | | | | | |
| 1 | Tabernaemontana macrocarpa | – | – | – | – | 1 | 1.28 (1.28 – 1.28) | 1 | 2.31 (2.31 – 2.31) |
| ARALIACEAE | | | | | | | | | |
| 1 | Aralia scandens | 1 | 0.8 (0.8 – 0.8) | 1 | 0.71 (0.71 – 0.71) | _ | – | – | – |
| ASTERACEAE | | | | | | | | | |
| 1 | Vernonia arborea | 8 | 7.06 (5.55 – 8.58) | 5 | 4.07 (2.8 – 5.35) | _ | – | – | – |
| 2 | Vernonia sp. | – | – | 2 | 0.98 (0.5 – 1.46) | _ | – | – | – |
| BURSERACEAE | | | | | | | | | |
| 1 | Canarium asperum | 1 | 0.84 (0.84 – 0.84) | 2 | 1.43 (0.73 – 2.14) | 1 | 1.8 (1.8 – 1.8) | 1 | 1.62 (1.62 – 1.62) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest 2005 n | Lowland Forest 2005 I.V.I | Lowland Forest 2009 n | Lowland Forest 2009 I.V.I | Lower Montane Forest 2005 n | Lower Montane Forest 2005 I.V.I | Lower Montane Forest 2009 n | Lower Montane Forest 2009 I.V.I |
|---|---|---|---|---|---|---|---|---|---|
| 2 | Canarium caudatum | – | – | – | – | 1 | 1.24 (1.24 – 1.24) | 1 | 2.02 (2.02 – 2.02) |
| 3 | Canarium decumanum | – | – | – | – | 1 | 2.99 (2.99 – 2.99) | 1 | 1.16 (1.16 – 1.16) |
| 4 | Canarium sp. | – | – | 1 | 0.68 (0.68 – 0.68) | _ | – | 1 | 1.46 (1.46 – 1.46) |
| 5 | Dacryodes longifolia | – | – | – | – | 3 | 3.39 (1.92 – 4.87) | 3 | 3.04 (1.72 – 4.36) |
| 6 | Dacryodes sp. | 1 | 0.79 (0.79 – 0.79) | 1 | 0.7 (0.7 – 0.7) | _ | – | – | – |
| 7 | Santiria apiculata | – | – | – | – | 2 | 2.43 (1.24 – 3.63) | 3 | 3.92 (2.21 – 5.63) |
| 8 | Santiria griffithii | – | – | – | – | 1 | 1.4 (1.4 – 1.4) | 1 | 1.23 (1.23 – 1.23) |
| CELASTRACEAE | | | | | | | | | |
| 1 | Bhesa paniculata | – | – | – | – | 2 | 2.38 (1.21 – 3.54) | 2 | 2.29 (1.17 – 3.41) |
| CHRYSOBALANACEAE | | | | | | | | | |
| 1 | Parinari elmeri | 1 | 0.99 (0.99 – 0.99) | 1 | 0.62 (0.62 – 0.62) | _ | – | – | – |
| 2 | Parinari sp. | 1 | 0.88 (0.88 – 0.88) | 1 | 0.76 (0.76 – 0.76) | _ | – | – | – |
| CLUSIACEAE | | | | | | | | | |
| 1 | Calophyllum sp. | 1 | 0.77 (0.77 – 0.77) | 1 | 0.69 (0.69 – 0.69) | _ | – | – | – |
| 2 | Garcinia caudiculata | 2 | 1.87 (0.95 – 2.78) | 2 | 1.67 (0.85 – 2.49) | _ | – | – | – |
| 3 | Garcinia forbesii | – | – | – | – | 3 | 3.12 (1.76 – 4.48) | 5 | 4.53 (3.11 – 5.95) |
| 4 | Garcinia maingayi | – | – | – | – | _ | – | 1 | 1.06 (1.06 – 1.06) |
| 5 | Garcinia mangostana | 1 | 0.8 (0.8 – 0.8) | 1 | 0.71 (0.71 – 0.71) | _ | – | – | – |
| 6 | Garcinia parvifolia | – | – | – | – | _ | – | 1 | 1.06 (1.06 – 1.06) |
| 7 | Garcinia sp. | 4 | 3.71 (2.35 – 5.08) | 4 | 3.27 (2.07 – 4.47) | 1 | 1.4 (1.4 – 1.4) | 1 | 1.29 (1.29 – 1.29) |
| 8 | Garcinia trianii | 2 | 1.59 (0.81 – 2.36) | 2 | 1.39 (0.71 – 2.08) | _ | – | – | – |
| CORNACEAE | | | | | | | | | |
| 1 | Mastixia rostrata | – | – | – | – | 6 | 6.05 (4.4 – 7.7) | 6 | 5.59 (4.07 – 7.11) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| CRYPTERONIACEAE | | | | | | | | | |
| 1 | Crypteronia paniculata | 1 | 7.17 (7.17 – 7.17) | 1 | 7.42 (7.42 – 7.42) | 2 | 3.46 (1.76 – 5.15) | 2 | 2.87 (1.46 – 4.27) |
| DIPTEROCARPACEAE | | | | | | | | | |
| 1 | Shorea macroptera | 1 | 0.88 (0.88 – 0.88) | 1 | 0.9 (0.9 – 0.9) | _ | – | – | – |
| 2 | Shorea ovata | 3 | 2.62 (1.48 – 3.76) | 3 | 2.51 (1.42 – 3.6) | _ | – | – | – |
| 3 | Shorea smithiana | 1 | 0.94 (0.94 – 0.94) | 1 | 0.82 (0.82 – 0.82) | _ | – | – | – |
| 4 | Shorea sp. | 1 | 0.99 (0.99 – 0.99) | 1 | 0.85 (0.85 – 0.85) | _ | – | – | – |
| EBENACEAE | | | | | | | | | |
| 1 | Diospyros macrophylla | 1 | 0.8 (0.8 – 0.8) | 1 | 0.73 (0.73 – 0.73) | _ | – | – | – |
| 2 | Diospyros sp. | – | – | 1 | 0.68 (0.68 – 0.68) | _ | – | – | – |
| ELAEOCARPACEAE | | | | | | | | | |
| 1 | Elaeocarpus clementis var. clemensiae | – | – | – | – | _ | – | 1 | 1.06 (1.06 – 1.06) |
| 2 | Elaeocarpus ferrugineus var. elliptifolius | – | – | – | – | _ | – | 1 | 1.12 (1.12 – 1.12) |
| ESCALLONIACEAE | | | | | | | | | |
| 1 | Polyosma latifolia | – | – | – | – | 5 | 7.27 (4.99 – 9.54) | 2 | 3.18 (1.62 – 4.74) |
| EUPHORBIACEAE | | | | | | | | | |
| 1 | Aporusa elmeri | 5 | 4.59 (3.15 – 6.03) | 5 | 3.9 (2.67 – 5.12) | _ | – | – | – |
| 2 | Aporusa grandistipula | – | – | – | – | _ | – | 1 | 1.1 (1.1 – 1.1) |
| 3 | Aporusa lucida | 1 | 0.77 (0.77 – 0.77) | 1 | 0.69 (0.69 – 0.69) | _ | – | – | – |
| 4 | Baccaurea bracteata | 2 | 1.6 (0.82 – 2.39) | 2 | 1.46 (0.75 – 2.18) | _ | – | – | – |
| 5 | Baccaurea macrocarpa | 1 | 0.78 (0.78 – 0.78) | 1 | 0.73 (0.73 – 0.73) | _ | – | – | – |
| 6 | Baccaurea tetrandra | 2 | 1.73 (0.88 – 2.58) | 3 | 2.21 (1.25 – 3.17) | _ | – | – | – |
| 7 | Blumeodendron sp. | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.07 (1.07 – 1.07) |
| 8 | Drypetes longifolia | – | – | – | – | 1 | 1.17 (1.17 – 1.17) | 1 | 1.08 (1.08 – 1.08) |

## Table 6. (Continued)

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| 9 | Drypetes sp. | – | – | 1 | 0.69 (0.69 – 0.69) | 1 | 1.23 (1.23 – 1.23) | 1 | 1.12 (1.12 – 1.12) |
| 10 | Glochidion rubrum | 1 | 0.97 (0.97 – 0.97) | 1 | 0.93 (0.93 – 0.93) | – | – | – | – |
| 11 | Glochidion sp. | – | – | 1 | 0.43 (0.43 – 0.43) | – | – | – | – |
| 12 | Macaranga aetheadenia | – | – | – | – | 1 | 1.19 (1.19 – 1.19) | 1 | 1.12 (1.12 – 1.12) |
| 13 | Macaranga beccariana | – | – | 4 | 2.58 (1.63 – 3.53) | – | – | – | – |
| 14 | Macaranga gigantea | 20 | 18.12 (16.43 – 19.8) | 21 | 18.18 (16.57 – 19.8) | – | – | – | – |
| 15 | Macaranga hypoleuca | 1 | 1.52 (1.52 – 1.52) | 1 | 1.43 (1.43 – 1.43) | – | – | – | – |
| 16 | Macaranga kinabaluensis | – | – | – | – | 14 | 12.77 (11.11 – 14.43) | 14 | 11.38 (9.9 – 12.86) |
| 17 | Macaranga pearsonii | 17 | 12.58 (11.21 – 13.94) | 21 | 15.3 (13.94 – 16.66) | – | – | – | – |
| 18 | Macaranga sp. | 1 | 0.79 (0.79 – 0.79) | 4 | 2.78 (1.76 – 3.8) | – | – | – | – |
| 19 | Macaranga triloba | 37 | 23.89 (22.66 – 25.12) | 45 | 25.36 (24.28 – 26.44) | – | – | – | – |
| 20 | Mallotus korthalsii | – | – | – | – | 3 | 3.49 (1.97 – 5.01) | 3 | 3.25 (1.84 – 4.67) |
| 21 | Mallotus paniculata | – | – | – | – | 1 | 1.17 (1.17 – 1.17) | – | – |
| 22 | Mallotus paniculatus | 53 | 37.21 (35.86 – 38.56) | 48 | 29.97 (28.77 – 31.17) | – | – | – | – |
| 23 | Pimeleodendron griffithianum | 2 | 3.37 (1.72 – 5.02) | 2 | 2.78 (1.42 – 4.15) | – | – | – | – |
| FABACEAE | | | | | | | | | |
| 1 | Spatholobus gyrocarpus | 1 | 0.99 (0.99 – 0.99) | 1 | 0.94 (0.94 – 0.94) | – | – | – | – |
| 2 | Spatholobus sp. | 1 | 0.79 (0.79 – 0.79) | 1 | 0.84 (0.84 – 0.84) | – | – | – | – |
| FAGACEAE | | | | | | | | | |
| 1 | Castanopsis cf.evansii | – | – | – | – | 1 | 1.25 (1.25 – 1.25) | 1 | 1.17 (1.17 – 1.17) |
| 2 | Castanopsis hypophoenicea | – | – | – | – | 1 | 1.25 (1.25 – 1.25) | 1 | 2.26 (2.26 – 2.26) |
| 3 | Castanopsis sp. | – | – | – | – | 1 | 1.53 (1.53 – 1.53) | 1 | 5.41 (5.41 – 5.41) |
| 4 | Lithocarpus cf. caudifolius | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.06 (1.06 – 1.06) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| 5 | Lithocarpus cf.gracilis | – | – | – | – | 1 | 2.34 (2.34 – 2.34) | 1 | 2.35 (2.35 – 2.35) |
| 6 | Lithocarpus cf.jacobsii | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | – | – |
| 7 | Lithocarpus gracilis | 5 | 4.31 (2.96 – 5.67) | 5 | 4.13 (2.83 – 5.42) | _ | – | – | – |
| 8 | Lithocarpus sp. | 1 | 0.88 (0.88 – 0.88) | 1 | 0.86 (0.86 – 0.86) | 3 | 6.82 (3.85 – 9.79) | 3 | 7.21 (4.07 – 10.35) |
| FLACOURTIACEAE | | | | | | | | | |
| 1 | Hydnocarpus sumatrana | – | – | – | – | 1 | 2.42 (2.42 – 2.42) | 1 | 2.3 (2.3 – 2.3) |
| 2 | Ryparosa cf.baccaureoides | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.06 (1.06 – 1.06) |
| HYPERICACEAE | | | | | | | | | |
| 1 | Cratoxylum arborescens | 1 | 0.85 (0.85 – 0.85) | 1 | 0.74 (0.74 – 0.74) | _ | – | – | – |
| 2 | Cratoxylum cochinchinense | 1 | 1.99 (1.99 – 1.99) | 1 | 1.72 (1.72 – 1.72) | _ | – | – | – |
| HYPHERICACEAE | | | | | | | | | |
| 1 | Cratoxylum sp. | – | – | 1 | 0.68 (0.68 – 0.68) | _ | – | – | – |
| ICACINACEAE | | | | | | | | | |
| 1 | Stemonurus malaccensis | – | – | – | – | 1 | 1.38 (1.38 – 1.38) | 1 | 1.32 (1.32 – 1.32) |
| IXONANTHACEAE | | | | | | | | | |
| 1 | Ixonanthes reticulata | 1 | 8.75 (8.75 – 8.75) | 1 | 10.74 (10.74 – 10.74) | _ | – | – | – |
| LAMIACEAE | | | | | | | | | |
| 1 | Vitex vestita | – | – | 1 | 0.7 (0.7 – 0.7) | _ | – | 2 | 2.15 (1.1 – 3.21) |
| LAURACEAE | | | | | | | | | |
| 1 | Alseodaphne oblanceolata | – | – | – | – | 1 | 1.27 (1.27 – 1.27) | 1 | 1.16 (1.16 – 1.16) |
| 2 | Alseodaphne sp. | 1 | 0.84 (0.84 – 0.84) | 1 | 0.85 (0.85 – 0.85) | _ | – | – | – |
| 3 | Beilschmiedia sp. | – | – | 1 | 0.69 (0.69 – 0.69) | _ | – | – | – |
| 4 | Cinnamomum griffithii | – | – | – | – | 2 | 3.01 (1.53 – 4.48) | 2 | 2.8 (1.43 – 4.18) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| 5 | Cryptocarya ferrea var. ferrea | – | – | – | – | 1 | 1.2 (1.2 – 1.2) | – | – |
| 6 | Cryptocarya sp. | – | – | – | – | 1 | 1.19 (1.19 – 1.19) | 1 | 1.09 (1.09 – 1.09) |
| 7 | Dehaasia caesia | 1 | 0.77 (0.77 – 0.77) | 1 | 0.7 (0.7 – 0.7) | _ | – | – | – |
| 8 | Dehaasia sp. | 2 | 1.56 (0.79 – 2.32) | 1 | 0.7 (0.7 – 0.7) | _ | – | – | – |
| 9 | Lindera lucida | 3 | 2.78 (1.57 – 3.99) | 3 | 2.56 (1.44 – 3.67) | _ | – | – | – |
| 10 | Lindera sp. | 2 | 1.7 (0.87 – 2.53) | 3 | 2.3 (1.3 – 3.3) | _ | – | – | – |
| 11 | Litsea caulocarpa | – | – | – | – | _ | – | 1 | 1.13 (1.13 – 1.13) |
| 12 | Litsea cylindrocarpa | – | – | – | – | 1 | 4 (4 – 4) | 1 | 4 (4 – 4) |
| 13 | Litsea grandis | – | – | – | – | 1 | 2.63 (2.63 – 2.63) | 1 | 2.11 (2.11 – 2.11) |
| 14 | Litsea sp. | 5 | 6.6 (4.53 – 8.67) | 7 | 6.68 (5.08 – 8.28) | 3 | 9.93 (5.6 – 14.25) | 4 | 10.44 (6.6 – 14.28) |
| 15 | Litsea subumbelliflora | 4 | 4.69 (2.97 – 6.41) | 4 | 4.21 (2.66 – 5.75) | _ | – | – | – |
| 16 | Neolitsea sp. | 2 | 2.22 (1.13 – 3.31) | 1 | 1.27 (1.27 – 1.27) | _ | – | – | – |
| LECYTHIDACEAE | | | | | | | | | |
| 1 | Barringtonia sarcostachys | 1 | 1.07 (1.07 – 1.07) | 1 | 0.92 (0.92 – 0.92) | _ | – | – | – |
| LOGANIACEAE | | | | | | | | | |
| 1 | Fagraea spicata | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.06 (1.06 – 1.06) |
| MAGNOLIACEAE | | | | | | | | | |
| 1 | Magnolia accuminata | 1 | 0.84 (0.84 – 0.84) | 1 | 0.74 (0.74 – 0.74) | _ | – | – | – |
| 2 | Magnolia candollii var.candollii | – | – | – | – | 4 | 20.19 (12.77 – 27.6) | 4 | 14.1 (8.92 – 19.28) |
| MELASTOMATACEAE | | | | | | | | | |
| 1 | Astronia cumingiana | – | – | – | – | 1 | 1.22 (1.22 – 1.22) | – | – |
| 2 | Memecylon beccarianum | 2 | 1.57 (0.8 – 2.34) | 2 | 1.4 (0.71 – 2.08) | 2 | 2.37 (1.21 – 3.53) | 2 | 2.16 (1.1 – 3.23) |
| 3 | Pternandra coerulescens | 1 | 1.57 (1.57 – 1.57) | 1 | 1.68 (1.68 – 1.68) | 3 | 4.72 (2.66 – 6.78) | 3 | 4.93 (2.78 – 7.08) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| MELIACEAE | | | | | | | | | |
| 1 | Aglaia crassinervia | – | – | – | – | 3 | 6.6 (3.73 – 9.48) | 2 | 5.59 (2.85 – 8.33) |
| 2 | Aglaia cumingiana | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | – | – |
| 3 | Aglaia forbesii | – | – | – | – | 2 | 2.37 (1.21 – 3.53) | 2 | 2.18 (1.11 – 3.25) |
| 4 | Aglaia leptantha | 1 | 0.79 (0.79 – 0.79) | 1 | 0.7 (0.7 – 0.7) | – | – | – | – |
| 5 | Aglaia leucophylla | – | – | – | – | 2 | 1.98 (1.01 – 2.94) | 1 | 1.28 (1.28 – 1.28) |
| 6 | Aglaia macrocarpa | – | – | – | – | 2 | 3.46 (1.76 – 5.15) | 2 | 3.12 (1.59 – 4.65) |
| 7 | Aglaia sp. | – | – | 1 | 0.68 (0.68 – 0.68) | 4 | 5.01 (3.17 – 6.85) | 4 | 4.59 (2.91 – 6.28) |
| 8 | Dysoxylum sp. | 8 | 6.35 (4.99 – 7.71) | 8 | 5.41 (4.25 – 6.57) | – | – | – | – |
| 9 | Sandoricum koetjape | 1 | 6.14 (6.14 – 6.14) | 1 | 5.21 (5.21 – 5.21) | – | – | – | – |
| 10 | Walsura pinnata | 1 | 0.84 (0.84 – 0.84) | 1 | 0.74 (0.74 – 0.74) | – | – | – | – |
| MORACEAE | | | | | | | | | |
| 1 | Artocarpus anisophyllus | 1 | 1.01 (1.01 – 1.01) | 1 | 0.9 (0.9 – 0.9) | – | – | – | – |
| 2 | Artocarpus anisophyllus var. sessilifolius | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 2 | 2.12 (1.08 – 3.16) |
| 3 | Artocarpus lanceifolius | – | – | – | – | 7 | 13.5 (10.26 – 16.74) | 7 | 12 (9.12 – 14.89) |
| 4 | Artocarpus odoratissimus | 3 | 2.49 (1.4 – 3.57) | 4 | 3.02 (1.91 – 4.14) | 1 | 3.19 (3.19 – 3.19) | 1 | 2.95 (2.95 – 2.95) |
| 5 | Artocarpus primackiana | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.25 (1.25 – 1.25) |
| 6 | Artocarpus sp. | 1 | 0.82 (0.82 – 0.82) | 4 | 2.43 (1.54 – 3.32) | – | – | – | – |
| 7 | Artocarpus teysmannii | – | – | – | – | 1 | 2.65 (2.65 – 2.65) | 1 | 2.49 (2.49 – 2.49) |
| 8 | Ficus fistulosa | 1 | 0.81 (0.81 – 0.81) | 1 | 0.75 (0.75 – 0.75) | – | – | – | – |
| 9 | Ficus fulva | 11 | 8.4 (7.04 – 9.77) | 12 | 7.88 (6.7 – 9.06) | – | – | – | – |
| 10 | Ficus hemsleyana | – | – | – | – | 1 | 1.18 (1.18 – 1.18) | 1 | 1.08 (1.08 – 1.08) |
| 11 | Ficus leptocalama | – | – | – | – | 1 | 1.19 (1.19 – 1.19) | 1 | 1.09 (1.09 – 1.09) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| 12 | Ficus megaleia | – | – | – | – | 2 | 2.34 (1.19 – 3.48) | 1 | 1.08 (1.08 – 1.08) |
| 13 | Ficus subterranea | 1 | 0.82 (0.82 – 0.82) | 1 | 0.74 (0.74 – 0.74) | _ | – | – | – |
| 14 | Ficus treubii | 1 | 0.83 (0.83 – 0.83) | – | – | _ | – | – | – |
| 15 | Ficus villosa | 1 | 0.81 (0.81 – 0.81) | 1 | 0.36 (0.36 – 0.36) | _ | – | – | – |
| 16 | Parartocarpus sp. | – | – | 1 | 0.7 (0.7 – 0.7) | _ | – | – | – |
| 17 | Prainea limpato | – | – | – | – | 1 | 1.19 (1.19 – 1.19) | 1 | 1.09 (1.09 – 1.09) |
| MYRISTICACEAE | | | | | | | | | |
| 1 | Gymnacranthera contracta | 1 | 0.79 (0.79 – 0.79) | 1 | 0.72 (0.72 – 0.72) | _ | – | – | – |
| 2 | Horsfieldia grandis | 2 | 1.67 (0.85 – 2.49) | 3 | 2.16 (1.22 – 3.1) | 1 | 1.23 (1.23 – 1.23) | 2 | 2.19 (1.12 – 3.27) |
| | Horsfieldia polyspherula | 1 | 0.78 (0.78 – 0.78) | 1 | 0.71 (0.71 – 0.71) | _ | – | – | – |
| | Knema cinerea | – | – | 3 | 2.06 (1.17 – 2.96) | _ | – | – | – |
| | Knema latifolia | 4 | 3.35 (2.12 – 4.58) | 4 | 2.98 (1.88 – 4.07) | _ | – | – | – |
| MYRSINACEAE | | | | | | | | | |
| 1 | Ardisia copelandii | – | – | – | – | 2 | 4.87 (2.48 – 7.25) | 2 | 5.91 (3.01 – 8.81) |
| 2 | Ardisia sp. | 1 | 1.01 (1.01 – 1.01) | 1 | 0.88 (0.88 – 0.88) | _ | – | – | – |
| MYRTACEAE | | | | | | | | | |
| 1 | Syzygium alcinae | – | – | – | – | 1 | 1.47 (1.47 – 1.47) | 1 | 1.35 (1.35 – 1.35) |
| 2 | Syzygium attenuata | – | – | – | – | 2 | 3.46 (1.77 – 5.16) | 2 | 3.02 (1.54 – 4.5) |
| 3 | Syzygium caudatilimbum | 2 | 1.99 (1.02 – 2.97) | 2 | 1.74 (0.89 – 2.59) | _ | – | – | – |
| 4 | Syzygium cerasiformis | – | – | – | – | _ | – | 1 | 1.12 (1.12 – 1.12) |
| 5 | Syzygium elliptilimba | 4 | 4.02 (2.54 – 5.5) | 4 | 3.3 (2.09 – 4.51) | _ | – | – | – |
| 6 | Syzygium fastigiata | – | – | – | – | 1 | 1.15 (1.15 – 1.15) | 1 | 1.06 (1.06 – 1.06) |
| 7 | Syzygium filiformis | – | – | – | – | 1 | 2.13 (2.13 – 2.13) | 1 | 1.94 (1.94 – 1.94) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| 8 | Syzygium javanica | – | – | – | – | _ | – | 1 | 1.12 (1.12 – 1.12) |
| 9 | Syzygium leucocladum | – | – | – | – | 2 | 1.72 (0.88 – 2.56) | 1 | 1.06 (1.06 – 1.06) |
| 10 | Syzygium lineata | – | – | – | – | 1 | 1.27 (1.27 – 1.27) | 1 | 1.15 (1.15 – 1.15) |
| 11 | Syzygium multibracteolata | – | – | – | – | 1 | 1.19 (1.19 – 1.19) | 1 | 1.1 (1.1 – 1.1) |
| 12 | Syzygium napiformis | 3 | 8.29 (4.68 – 11.89) | 3 | 7.01 (3.96 – 10.06) | _ | – | – | – |
| 13 | Syzygium nehardsii | – | – | – | – | 1 | 1.18 (1.18 – 1.18) | 1 | 1.09 (1.09 – 1.09) |
| 14 | Syzygium sandakanensis | – | – | 1 | 0.68 (0.68 – 0.68) | _ | – | – | – |
| 15 | Syzygium sp. | 6 | 5.03 (3.66 – 6.4) | 7 | 4.75 (3.61 – 5.88) | 2 | 6.18 (3.15 – 9.21) | 3 | 3.08 (1.74 – 4.42) |
| 16 | Syzygium treubii | – | – | – | – | 3 | 6.57 (3.71 – 9.44) | 3 | 6.09 (3.44 – 8.74) |
| OLACACEAE | | | | | | | | | |
| 1 | Ochanostachys amentacea | 3 | 2.38 (1.34 – 3.41) | 3 | 2.07 (1.17 – 2.98) | _ | – | – | – |
| OLEACEAE | | | | | | | | | |
| 1 | Chionanthus pluriflorus | – | – | – | – | 3 | 3.47 (1.96 – 4.98) | 2 | 2.13 (1.09 – 3.18) |
| 2 | Chionanthus polygamus | – | – | – | – | 1 | 1.46 (1.46 – 1.46) | 1 | 1.33 (1.33 – 1.33) |
| POLYGALACEAE | | | | | | | | | |
| 1 | Xanthophyllum obscurum | 3 | 2.88 (1.63 – 4.13) | 3 | 2.39 (1.35 – 3.44) | _ | – | – | – |
| 2 | Xanthophyllum flavescens | – | – | – | – | 3 | 1.74 (0.98 – 2.5) | 3 | 1.57 (0.89 – 2.26) |
| 3 | Xanthophyllum penibukanense | – | – | – | – | 2 | 2.35 (1.2 – 3.5) | 2 | 2.15 (1.1 – 3.2) |
| 4 | Xanthophyllum sp. | 6 | 6.13 (4.46 – 7.8) | 5 | 4.05 (2.78 – 5.32) | _ | – | – | – |
| 5 | Xanthophyllum subcoriaceum | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 2 | 2.33 (1.19 – 3.48) |
| 6 | Xanthophyllum velutinum | – | – | – | – | _ | – | 2 | 1.56 (0.8 – 2.32) |
| RHAMNACEAE | | | | | | | | | |
| 1 | Ziziphus angustifolius | – | – | – | – | 1 | 1.29 (1.29 – 1.29) | 1 | 1.18 (1.18 – 1.18) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| RHIZOPHORACEAE | | | | | | | | | |
| 1 | Pellacalyx lobbii | 1 | 1.05 (1.05 – 1.05) | 1 | 1.14 (1.14 – 1.14) | _ | – | – | – |
| ROSACEAE | | | | | | | | | |
| 1 | Prunus javanica | 4 | 2.83 (1.79 – 3.87) | 5 | 3.23 (2.22 – 4.24) | _ | – | – | – |
| 2 | Prunus sp. | – | – | 3 | 1.66 (0.94 – 2.39) | 1 | 3.88 (3.88 – 3.88) | 1 | 3.59 (3.59 – 3.59) |
| RUBIACEAE | | | | | | | | | |
| 1 | Diplospora singularis | – | – | – | – | 1 | 1.18 (1.18 – 1.18) | 2 | 2.08 (1.06 – 3.09) |
| 2 | Discospermum abnorme | – | – | – | – | 3 | 3.85 (2.17 – 5.52) | 3 | 3.56 (2.01 – 5.11) |
| 3 | Gardenia tubifera | – | – | – | – | 1 | 1.16 (1.16 – 1.16) | 1 | 1.06 (1.06 – 1.06) |
| 4 | Metadina trichotoma | 1 | 3.38 (3.38 – 3.38) | 1 | 3.13 (3.13 – 3.13) | _ | – | – | – |
| 5 | Pleiocarpidia sp. | 3 | 1.94 (1.09 – 2.78) | 2 | 1.48 (0.76 – 2.21) | _ | – | – | – |
| 6 | Porterandia chanii | 3 | 2.8 (1.58 – 4.02) | 3 | 2.51 (1.42 – 3.61) | _ | – | – | – |
| 7 | Prismatomeris tetrandra | – | – | – | – | _ | – | 1 | 1.09 (1.09 – 1.09) |
| 8 | Rothmannia pseudoternifolia var. pseudoternifolia | – | – | – | – | 3 | 3.5 (1.97 – 5.02) | 3 | 3.77 (2.13 – 5.42) |
| 9 | Tarenna cumingiana | – | – | – | – | 2 | 2.44 (1.24 – 3.64) | 2 | 2.25 (1.15 – 3.35) |
| 10 | Tarenna sp. | – | – | 1 | 0.68 (0.68 – 0.68) | 2 | 2.47 (1.26 – 3.68) | 1 | 1.11 (1.11 – 1.11) |
| 11 | Timonius flavescens | 1 | 0.78 (0.78 – 0.78) | 1 | 0.69 (0.69 – 0.69) | _ | – | – | – |
| 12 | Urophyllum glabrum | – | – | – | – | 1 | 1.19 (1.19 – 1.19) | 1 | 1.1 (1.1 – 1.1) |
| 13 | Urophyllum sp. | 1 | 0.77 (0.77 – 0.77) | 1 | 0.3 (0.3 – 0.3) | _ | – | – | – |
| RUTACEAE | | | | | | | | | |
| 1 | Maclurodendron porteri | – | – | – | – | 3 | 7.45 (4.21 – 10.7) | 3 | 8.56 (4.83 – 12.29) |
| SABIACEAE | | | | | | | | | |
| 1 | Meliosma sumatrana | 1 | 0.77 (0.77 – 0.77) | – | – | 8 | 9.65 (7.58 – 11.72) | 9 | 9.38 (7.57 – 11.2) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| SAPINDACEAE | | | | | | | | | |
| 1 | Gymnacranthera contracta | – | – | 1 | 0.71 (0.71 – 0.71) | _ | – | – | – |
| 2 | Harpullia sp. | 3 | 1.51 (0.85 – 2.17) | 3 | 1.32 (0.75 – 1.9) | _ | – | – | – |
| 3 | Lepisanthes amoena | – | – | – | – | 1 | 1.15 (1.15 – 1.15) | 1 | 1.1 (1.1 – 1.1) |
| 4 | Nephelium cuspidatum | 3 | 1.94 (1.09 – 2.78) | 5 | 2.73 (1.87 – 3.58) | _ | – | – | – |
| 5 | Nephelium maingayi | 1 | 0.78 (0.78 – 0.78) | 1 | 0.71 (0.71 – 0.71) | 2 | 2.93 (1.5 – 4.37) | 2 | 2.21 (1.13 – 3.29) |
| 6 | Nephelium ramboutan-ake | 2 | 1.64 (0.84 – 2.44) | 2 | 1.48 (0.76 – 2.21) | _ | – | – | – |
| 7 | Nephelium sp. | 1 | 0.91 (0.91 – 0.91) | 1 | 0.82 (0.82 – 0.82) | _ | – | – | – |
| SAPOTACEAE | | | | | | | | | |
| 1 | Palaquium rostratum | – | – | – | – | 2 | 2.47 (1.26 – 3.68) | 1 | 1.26 (1.26 – 1.26) |
| 2 | Palaquium sericeum | 1 | 0.94 (0.94 – 0.94) | 1 | 0.84 (0.84 – 0.84) | _ | – | – | – |
| 3 | Payena microphylla | 1 | 1.11 (1.11 – 1.11) | 1 | 0.99 (0.99 – 0.99) | _ | – | – | – |
| SAXIFRAGACEAE | | | | | | | | | |
| 1 | Polyosma latifolia | – | – | – | – | _ | – | 3 | 4.19 (2.37 – 6.02) |
| STERCULIACEAE | | | | | | | | | |
| 1 | Scaphium macropodum | 8 | 7.6 (5.97 – 9.22) | 10 | 8.3 (6.83 – 9.76) | _ | – | – | – |
| 2 | Sterculia sp. | – | – | 1 | 0.68 (0.68 – 0.68) | _ | – | – | – |
| SYMPLOCACEAE | | | | | | | | | |
| 1 | Symplocos fasciculata | 1 | 1.34 (1.34 – 1.34) | 1 | 1.32 (1.32 – 1.32) | _ | – | – | – |
| THEACEAE | | | | | | | | | |
| 1 | Adinandra dumosa | – | – | – | – | 1 | 3.78 (3.78 – 3.78) | 1 | 3.31 (3.31 – 3.31) |
| 2 | Pyrenaria sp. | – | – | – | – | _ | – | 1 | 1.07 (1.07 – 1.07) |
| 3 | Schima wallichii | – | – | – | – | 2 | 11.46 (5.84 – 17.07) | 2 | 10.78 (5.5 – 16.06) |

**Table 6. (Continued)**

| | Family/Species | Lowland Forest | | | | Lower Montane Forest | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2005 | | 2009 | | 2005 | | 2009 | |
| | | n | I.V.I | n | I.V.I | n | I.V.I | n | I.V.I |
| THYMELAEACEAE | | | | | | | | | |
| 1 | Aquilaria malaccensis | 1 | 0.84 (0.84 – 0.84) | 2 | 1.41 (0.72 – 2.11) | – | – | 1 | 1.06 (1.06 – 1.06) |
| 2 | Gonystylus forbesii | – | – | – | – | 2 | 2.06 (1.05 – 3.08) | 8 | 6.32 (4.97 – 7.68) |
| TILIACEAE | | | | | | | | | |
| 1 | Microcos elmeri | 1 | 0.93 (0.93 – 0.93) | 2 | 1.49 (0.76 – 2.22) | – | – | – | – |
| 2 | Microcos sp. | – | – | – | – | – | – | 1 | 1.2 (1.2 – 1.2) |
| 3 | Microcos triflora | 1 | 0.77 (0.77 – 0.77) | 1 | 0.69 (0.69 – 0.69) | – | – | – | – |
| ULMACEAE | | | | | | | | | |
| 1 | Gironniera subaequalis | – | – | – | – | 3 | 3.56 (2.01 – 5.1) | 2 | 2.19 (1.12 – 3.26) |
| 2 | Trema orientalis | 3 | 3.81 (2.15 – 5.47) | 2 | 2.12 (1.08 – 3.17) | – | – | – | – |
| VERBENACEAE | | | | | | | | | |
| 1 | Vitex vestita | 1 | 1.15 (1.15 – 1.15) | – | – | 2 | 2.33 (1.19 – 3.48) | – | – |

# Chapter 3

## Forest Structure Dynamics in Selectively Logged Lowland and Hill Dipterocarp Forest of Sabah Malaysian Borneo.

**Abstract**

Rapid decreases in the area of old growth tropical forest has increased the importance of gaining a better understanding of the ecology of the logged forest habitats that are expanding in extent. The focus of this study is to examine tree aboveground carbon stocks and their relationship with tree diversity in lowland and hill dipterocarp forest 14 years after selective logging. Nine permanent plots of 20 x 50 m (0.1 ha) were established along 3 km transects crossing the lowland and hill dipterocarp forests at the edge of the Imbak Canyon Conservation Area in Central Sabah. A total of 871 trees belonging to 39 plant families and 133 species were sampled. Tree species diversity, tree density, tree stand basal area and tree aboveground carbon varied between lowland (up to 300 m asl.) and hill dipterocarp (300 – 750 m asl.) forest. Dipterocarpaceae, Euphorbiaceae, Myrtaceae and Lauraceae were the most common families recorded in both types of forests. *Macaranga depressa*, *Eugenia* spp., *Aglaia korthalsii, Litsea* spp., *Palaquium* spp. and *Shorea macrophylla* had higher Importance Value Index scores (IVI) in hill dipterocarp forest whereas *Eugenia* spp., *Macaranga depressa, Mallotus* spp., *Shorea macroptera, Litsea* spp. and *Macaranga hypoleuca* had higher Importance Value Index scores in lowland dipterocarp forest and could therefore be considered the common species. The Shannon diversity index for both vegetation types was higher in trees of dbh class of 5 – 10 cm, followed by trees of 11 – 20 cm dbh and 21 – 40 cm dbh. There were no trees of > 60 cm dbh in hill dipterocarp forest. Tree densities were higher in hill dipterocarp forest with 1,080 trees $ha^{-1}$ (95% CI: 1010 – 1150) in contrast to lowland dipterocarp forest with 914 trees $ha^{-1}$ (95% CI: 852 – 976). Lowland dipterocarp forest however showed higher tree stand basal area of 14.49 $m^2$ $ha^{-1}$ (95% CI: 11.79 – 17.67) and tree aboveground carbon of 123.13 Mg C $ha^{-1}$ (95% CI: 95.38 – 157.38), in contrast to hill dipterocarp forest which contained a lower tree stand basal area of 7.32 $m^2$ $ha^{-1}$ (95% CI: 6.23 – 8.51) and tree

aboveground carbon of 56.11 Mg C $ha^{-1}$ (95% CI: 43.06 – 71.41). My data documents the differences in diversity, structure and function between secondary lowland and hill dipterocarp forests 14 years after selective logging.

**Introduction**

The rapid decline in the extent of old growth forest has increased the relative importance of understanding the dynamics of logged forest habitats (Berry *et al.*, 2010). The viability of sustainable forest management is largely contingent on the severity of past logging practices (Kleine & Heuveldop, 1993). Timber production in commercial forest areas in SE Asia has often involved selective logging removing only commercial stems over a minimum diameter at breast height limit (Bischoff *et al.*, 2005; Okuda *et al.*, 2003; Pinard & Cropper, 2000). Sustainable management (Appanah and Weinland, 1990) and reduced impact logging guidelines (Pinard *et al.,* 2000; Sist *et al.*, 1998) have been developed to minimise damage, but these have rarely been implemented on an operational scale.

Evaluation of forest structure in selectively logged forest is important to provide empirical information for harvesting plans and management strategies. As an example, tree basal area, tree density and species composition can be used to estimate the volume of timber production for logging rotations. This may also indicate disturbance intensity that may be useful to assess the capability for forest recovery. Furthermore, these measures are crucial as they can be used as tools to identify the appropriate silvicultural treatment and type of tree species to be used in restoration.

Impacts of past disturbance have changed the species composition in selectively logged forest. Logging can change the species composition and the growth of individual tress of all tree sizes (Cannon *et al.,* 1993; Saiful, 2014). Soil and altitude also influence the process of forest recovery. Several studies have been carried out on the immediate effects of different logging intensity and techniques to forest succession (Bertault & Sist, 1997;

Pinard *et al*., 2000; Seng *et al.*, 2004) with higher logging intensity resulting in greater damage and inhibiting recovery (Cole *et al.*, 2013; Jones & Schmitz, 2009). Cole *et al*., (2013) estimated that severely logged forest in SE Asia could take longer that 400 years to recover its structure – considerably longer than in comparable forest in Central America, Africa and South America.

Several studies have examined the effects of selective logging on forest dynamics (Kuusipalo *et al.*, 1995; Newbery *et al.*, 1992; Okuda *et al.*, 2003; Saiful, 2014; Verburg & van Eijk-Bos, 2003) and a number of researchers have reported that vegetation characteristics differ between lowland and hill dipterocarp forests (Fox, 1978; Meijer & Wood, 1964; Whitmore *et al.*, 1990). The focus of this study is to combine these two topics by comparing the differences of forest dynamics among selectively logged forest in lowland and hill dipterocarp forest after 14 years of natural recovery following selective logging. The specific objectives were to (1) determine forest characteristics in lowland dipterocarp forest and hill dipterocarp forest based on tree density, tree basal area, and tree species diversity; and (2) to compare the tree aboveground carbon stocks between lowland dipterocarp forest and hill dipterocarp forest.

## Methods

### Study Area

The study area is located at the edge of the Imbak Canyon Conservation Area (ICCA). The area is adjacent to the upper Sungai Kinabatangan and part of Sg. Pinangah Forest Reserve, a class II commercial forest concession managed by the Sabah Foundation. The area was selectively logged in late 1995 and then again in 2009. The soil type in ICCA and the surrounding area is a mixture of sandstone and mudstone with fine to coarse texture. Elevation ranges from 200 – 1500 m above sea level. The area receives an average of 2500 – 3500 mm rainfall annually and the monthly temperature ranges from 28 – 32$^{o}$C (Daim *et al.,* 2011; Kammesheidt *et al.*, 2009). In general, the vegetation types of undisturbed lowland and hill forest was characterized by a high proportion of species from the Dipterocarpaceae family (Whitmore *et al.*, 1990).

### Sampling and tree measurement

I established nine permanent sampling plot of sizes 20 x 50 m (0.1 ha) along a transect in logged forest across an altitude range from 120 to 800 m above sea level. I categorised the sampling plots according to the two forest types: (1) lowland dipterocarp forest with an altitudinal range from 120 – 300 m; and (2) hill dipterocarp forest with an altitudinal range from 300 to 600 m (Figure 1). I established five plots in lowland dipterocarp forest and four plots in hill dipterocarp forest (Table 1). Plots were established every 50 m along a 500 m transect line in lowland dipterocarp forest and a 500 m transect line in hill dipterocarp forest (Figure. 2). However, one plot in hill dipterocarp was forest damaged due to the on-going logging activities during the inventory work. This, made an unbalanced sample plots with only four sampling plots in the hill dipterocarp forest and five sampling plots in the lowland dipterocarp forest.

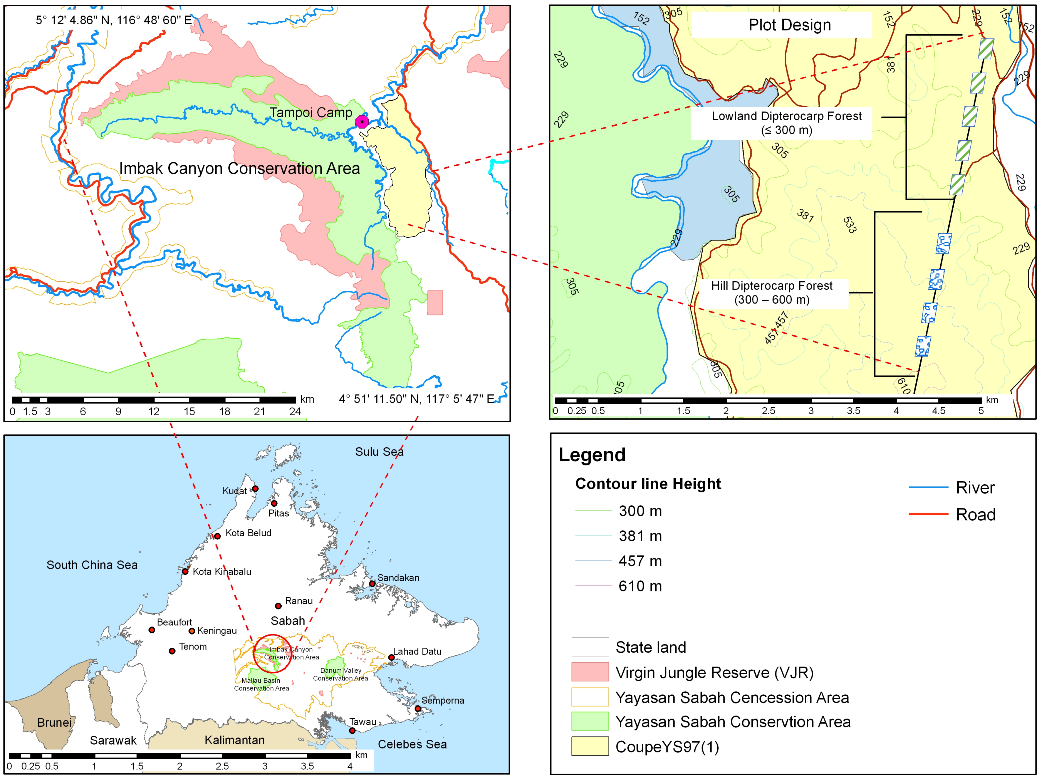


**Figure 1.** Location of the study area showing the experimental design.

**Table 1.** List of sub plots with size of area and total number of stems in both selectively logged lowland dipterocarp and hill dipterocarp forest.

| **Lowland dipterocarp** | | | | **Hill dipterocarp** | | | |
|---|---|---|---|---|---|---|---|
| Plot | Elevation (m) | Size (ha) | Number of stems (n) | Plot | Elevation (m) | Size (ha) | Number of stems (n) |
| P1 | 120 | 0.1 | 116 | P6 | 420 | 0.1 | 111 |
| P2 | 160 | 0.1 | 119 | P7 | 480 | 0.1 | 140 |
| P3 | 200 | 0.1 | 91 | P8 | 530 | 0.1 | 89 |
| P4 | 250 | 0.1 | 58 | P9 | 590 | 0.1 | 94 |
| P5 | 280 | 0.1 | | | | | |
| **Total** | **435** | **0.5** | | **Total** | | **0.4** | **434** |

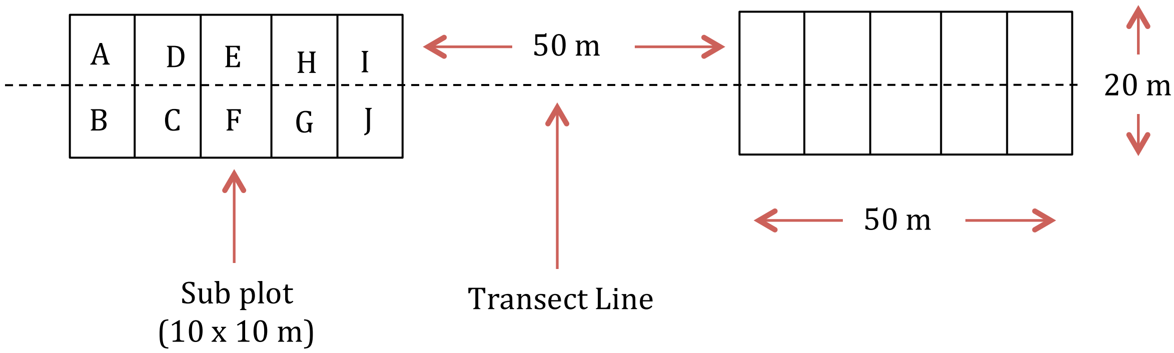


**Figure 2.** Schematic of the permanent sampling plot design and sizes.

I conducted three forest inventories; the first measurement was in July 2009, the second in October 2010 and the third in November 2012. The second measurement was conducted a year after the second logging in October 2010. In this study I use the 2009 measurement to establish the post logging information of the forest dynamics after 14 years of recovery from selective logging in 1995. Trees greater than 5 cm diameter at breast height (dbh) were tagged, identified and measured for dbh and height. The dbh was categorized into six size groups: 5 – 10 cm dbh, 11 – 20 cm, 21 – 40 cm, 41 – 60 cm, 61 – 80 cm.

**Forest structure, diversity and carbon stocks**

Tree basal area, density, species diversity and tree aboveground carbon stocks varied between lowland and hill dipterocarp forest. The Shannon-Wiener index and Shannon equitability was calculated to evaluated the tree species diversity as follows:

***Shannon–Wiener Index:***

$$H' = -\sum_{I=1} (P_i)\,(\ln P_i)$$

Where $H'$ = Index of species diversity, $P_i$ =Proportional abundance of the $i$th species = (ni /N).

***Shannon's equitability ($E_H$):***

$$E_H = H/H_{max} = H/lnS$$

Shannon's equitability ($E_H$) measures the evenness of a community and can be calculated by dividing $H$ by $H_{max}$ (here $H_{max}$ = ln$S$). Equitability (evenness) assumes a value between 0 and 1(complete evenness).

***Important Value Index (IVI)***

The importance value index (IVI) (Curtis & McIntosh, 1951; Whittaker, 1970) was used to investigate role of the species composition to the community structure in the plots and was calculated as the sum of variables in; i) relative dominance, ii) relative density and iii) relative frequency. The IVI formular and each variable were calculated as follows:

- Relative dominance = (total basal area for a species / total basal area for all species) x 100
- Relative density = (number of individual of a species / total number of individual) x 100
- Relative frequency = (frequency of a species / sum frequencies of all species) x 100
- IVI = relative dominance + relative dominance + relative frequency

***Aboveground biomass and Cabon Sequestration***

To assess carbon stocks on each site, I used tree dbh and wood density to predict aboveground carbon stocks. I used the existing allometric equations [ln(TAGB)=c+αln(dbh)+βln(WD)] of mixed species group derived from Basuki *et al.*(2009) where TAGB is the Total aboveground biomass in kg tree$^{-1}$. The values for c (intercept), α and β (slope coefficients) of the regression differ due to species grouping. WD is wood density in g cm$^{-3}$. Wood density values were referred to agroforestry database (http://db.worldagroforestry.org/wd). When not available, the wood density values were taken from the most closely related species. Tree aboveground carbon was estimated as 50% of tree above ground biomass (Nepstad *et al.*, 1994).

**Analysis**

The tree density was calculated for each dbh class and type of selectively logged forest separately. Tree density, canopy height, basal area and tree aboveground carbon stocks were calculated and categorised according to dbh classes of 5 – 10 cm, 11 – 20 cm, 21 – 40 cm, 41 – 60 cm and 61 – 80 cm. I used a general linear model (glm) with Gamma distribution and log link function to compare the effects of tree dbh classes and treatment. All mean estimates were presented with lower and upper limits of 95% confidence interval (CI). All analyses were performed with the R statistical software version 2.15.0 (R Core Development Team 2012).

**Table 2**. Model description of the total aboveground biomass of Dipterocarp forest. The unit for TAGB is in kg/tree, DBH is in cm, C is the intercept, and α is the slope coefficient of the regression (from Basuki *et al.*, 2009).

| Coefficient | *Dipterocarpus* | *Hopea* | *Palaquium* | *Shorea* | Commercial species | Mixed species |
|---|---|---|---|---|---|---|
| C | –1.190 | –1.708 | –0.723 | –1.708 | –1.045 | –0.744 |
| α | 2.175 | 2.335 | 2.145 | 2.335 | 2.203 | 2.188 |
| β | 0.082 | 0.174 | 0.704 | 0.174 | 0.639 | 0.832 |

Notes:

- Commercial species (was constructed from the mix genera of *Dipterocarpus, Hopea, Palaquium* and *Shorea*).
- Mixed species (was constructed from commercial and non-commercial species).

## Results

*Forest structure*

I sampled 867 stems ≥ 5.0 cm dbh across the permanent sampling plots in lowland and hill dipterocarp forest. Tree density was higher in hill dipterocarp forest with 1,080 trees ha$^{-1}$ (95% CI: 1,010– 1,150) versus 914 trees ha$^{-1}$ (95% CI: 855– 976) in lowland dipterocarp forest. The distribution of tree density and tree basal area by dbh size class shows a contrasting pattern between the forest types (Table 3). Hill dipterocarp forest contained fewer large trees (7 trees) above 41 cm dbh and no trees above 61 cm dbh in comparison lowland dipterocarp forest with 17 and 11 trees respectively. In general, the smallest dbh size contributed the most into tree density values (Figure 3a) and the larger classes to basal area (Figure 3c). The mean tree basal area in lowland dipterocarp forest was 14.49 m$^2$ ha$^{-1}$ (95% CI: 11.79 – 17.67) compared to 7.32 m$^2$ ha$^{-1}$ (95% CI: 6.23 – 8.51) in hill dipterocap forest (Table 3).

Mean tree height ranged from 7.59 m (95% CI: 6.60 – 8.70) to 31.18 m (95% CI: 26.99 – 35.87) in lowland dipterocarp forest and from 8.18 m (95% CI: 6.87 – 9.68) to 23.14 m (95% CI: 17.98 – 29.07) in the hill dipterocarp (Figure 3b; Table 3). The data distribution shows that the tree height range is 32 m in lowland dipterocarp forest and 40 m in in the hill dipterocarp. Less than half of the trees heights are below 9 m and more than half are 9 m and above. The median for both both lowland dipterocarp and hill dipterocarp forest have similar and show no significant on the trees median (9 m) (Figure 4).

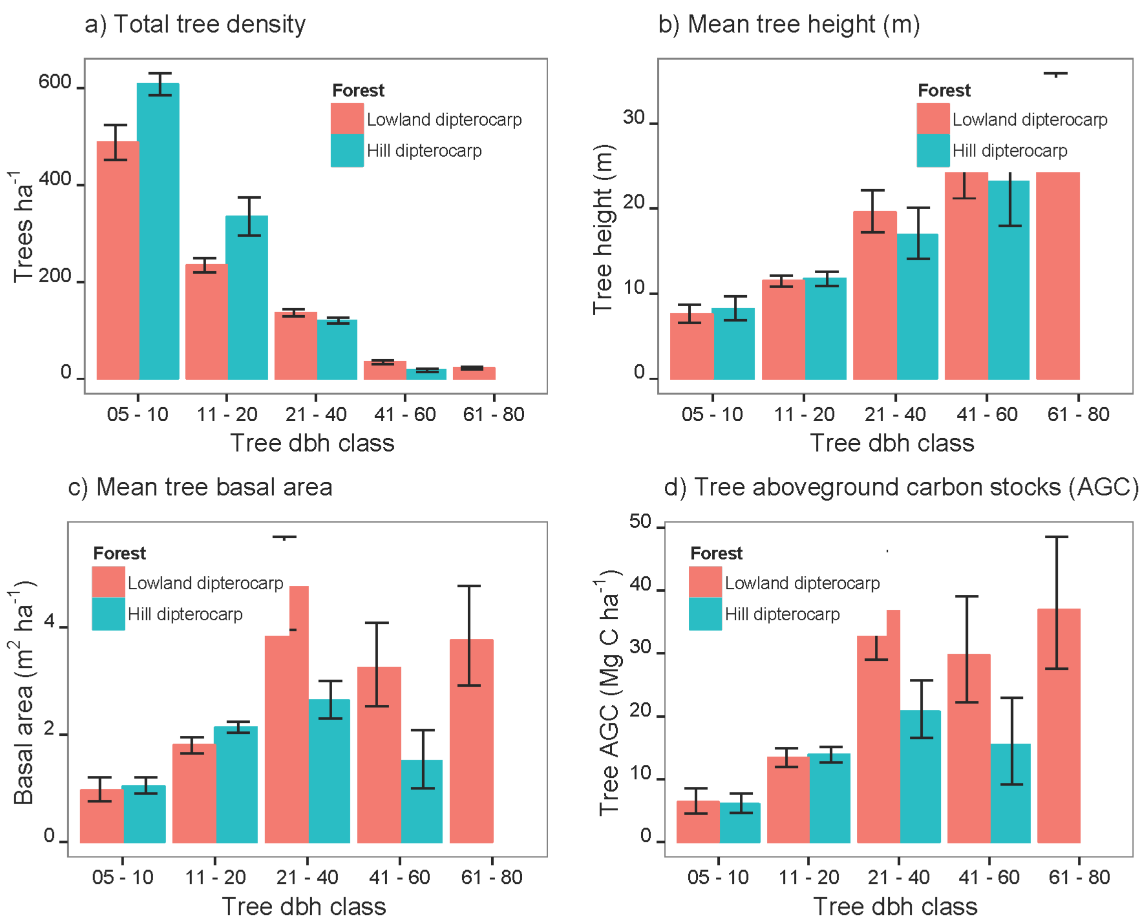


**Figure 3.** Pattern of forest structure dynamics between lowland and hill dipterocarp forest. Graphs represent (a) tree density, (b) mean of tree height by dbh class, (c) mean of tree basal area, and (d) tree aboveground carbon stocks with. The bar is 95% confidence intervals (calculated from the glm model).

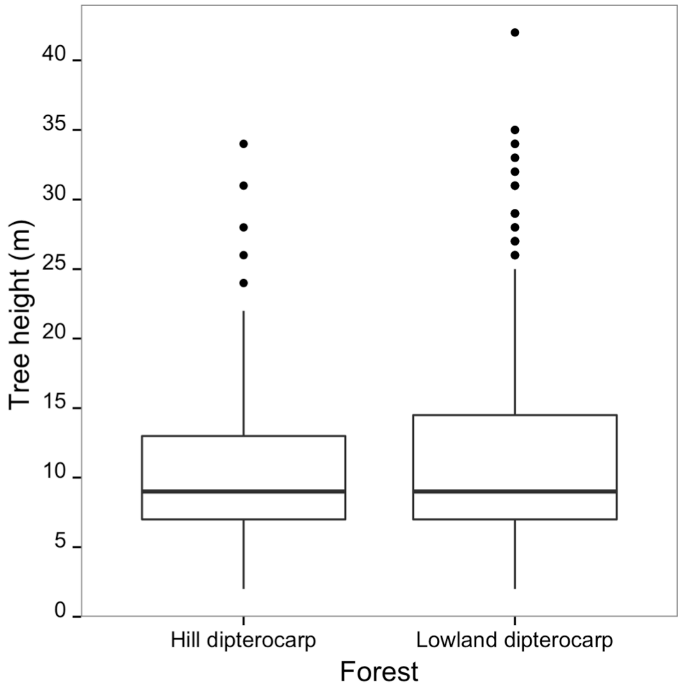


**Figure 4.** Tree heights distribution and range in lowland and hill dipterocarp forest.

*Tree aboveground carbon (AGC) stocks*

Tree aboveground carbon stocks of 123.13 Mg C ha$^{-1}$ (95% CI: 95.38 – 157.38) in lowland dipterocarp forest were significantly higher more than double compared to 56.11 Mg C ha$^{-1}$ (95% CI: 43.06 – 71.41) in hill dipterocarp forest (Table 3). Large trees with dbh size classes of 61 – 80 cm with 36.93 Mg C ha$^{-1}$ (95% CI: 27.61 – 48.55) and trees with dbh size classes of 21 – 40 cm with 36.72 Mg C ha$^{-1}$ (95% CI: 29.04 – 46.29) contributed most into tree aboveground carbon stocks values both in lowland dipterocarp forest and trees with dbh size classes of 21 – 40 cm with 20.73 Mg C ha$^{-1}$ (95% CI: 16.58 – 25.67) in hill dipterocarp forest (Figure 3d). Trees in dbh size class of 21 – 40 cm, 41 – 60 cm and 61 – 80 cm were larger contributors to aboveground carbon stocks in lowland dipterocarp forest. Meanwhile, the main contributors to tree aboveground carbon stocks in hill dipetrocarp forest were trees of dbh size 11 – 20 cm, 21 – 40 cm and 41 – 60 cm.

*Vegetation floristic and diversity*

The most common families were Dipterocarpaceae (26.2%), Euphorbiaceae (26.2%), Myrtaceae (7.6%) and Lauraceae (4.6%) in the lowland forest, and Euphorbiaceae (27.5%), Dipterocarpaceae (27.2%), Meliaceae (6.5%) and Myrtaceae (5.8%) in hill dipterocarp forest (Figure 5a; Table 3). The number of species and families varied between forest types. There were 29 families and 84 species in lowland dipterocarp forest versus 35 families and 77 species in hill dipterocarp forest (Table 4).

Diversity and evenness values based on the Shannon index decreased with increasing dbh in both lowland and hill dipterocarp forest (Figure 5c; Table 5). Lowland dipterocarp forest had higher diversity and evenness in most dbh size classes compared to hill dipterocarp forest. However, in the dbh size class 21 – 40 cm both forest types showed similar evenness (Table 5). The vegetation importance values showed differences in species among forest types (Figure 5b; Table 6). Species of *Eugenia, Macaranga depressa, Mollotus* spp. (Euphorbiaceae) and *Shorea macroptera* (Dipterocarpaceae) were the most common species in lowland dipterocarp forest. In hill dipterocarp forest, *Macaranga depressa* (Euphorbiaceae) was the most common species followed by *Eugenia* spp. (Myrtaceae)*, Aglaia korthalsii* (Meliaceae) and *Litsea* spp. (Lauraceae) (Table 6).

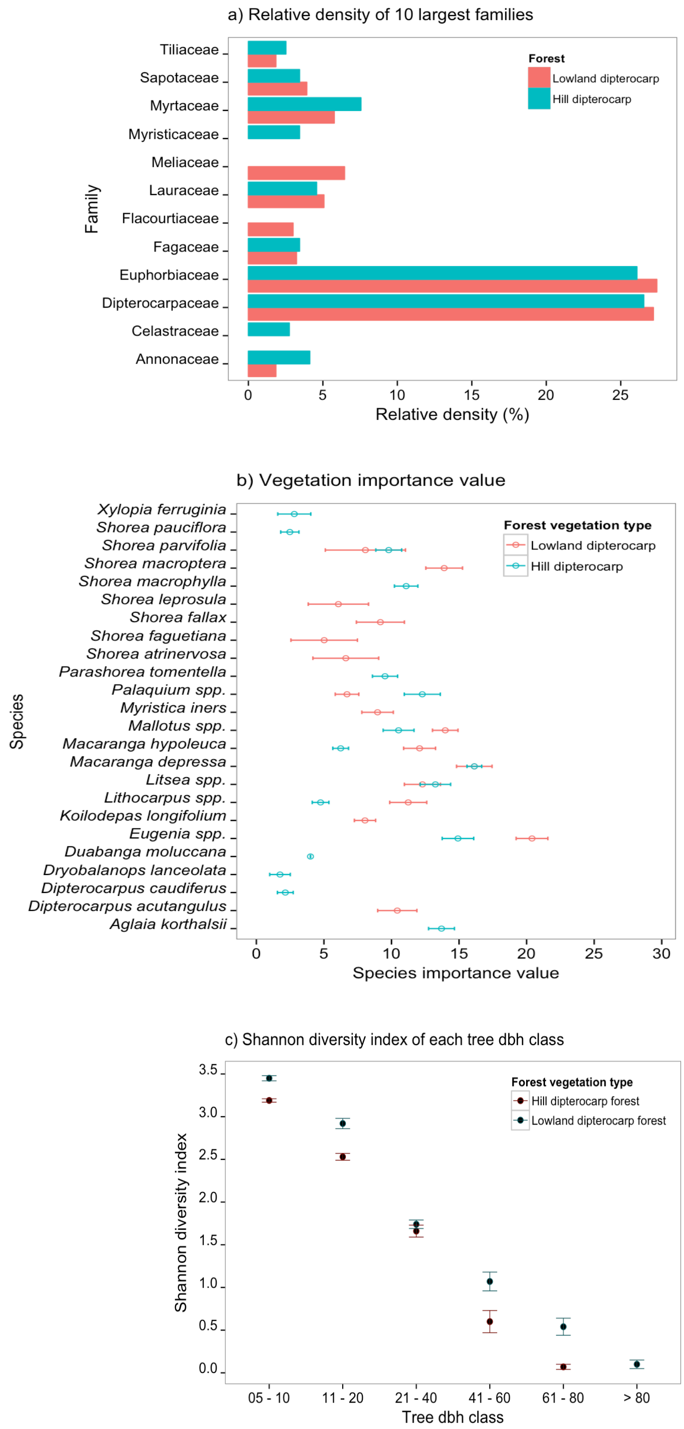


**Figure 5.** Tree composition, vegetation importance value and diversity: a) Relative density of 10 largest families, b) vegetation importance value and c) Shannon diversity index. The bar show 95% confidence intervals (calculated for each dbh class and type of selectively logged forest separately).

**Table 3.** Tree density, mean tree height, mean tree basal area and mean tree aboveground carbon (AGC) stocks with 95% CIs by dbh size class in selectively logged lowland diptercoarp forest and hill dipterocarp forest. (n) is the total number of trees sampled. Tree density was calculated for each dbh class and type of selectively logged forest separately. The means and 95% Confidence Interval (CI) for both basal area and tree aboveground carbon were estimated using general linear model with Gamma family and ^sqrt link.

| | **Lowland diptercoarp forest** | | | | | **Hill dipterocarp forest** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| dbh Classes | n | Tree density (Trees ha-1) | Mean of tree height (m) | Mean of tree basal area ($m^2$ $ha^{-1}$) | Mean of tree AGC stocks (Mg C $ha^{-1}$) | n | Tree density (Trees ha-1) | Mean of tree height (m) | Mean of tree basal area ($m^2$ $ha^{-1}$) | Mean of tree AGC stocks (Mg C $ha^{-1}$) |
| 5 – 10 | 222 | 488 (453 – 523) | 7.59 (6.6 – 8.7) | 0.96 (0.76 – 1.2) | 6.35 (4.57 – 8.57) | 243 | 608 (585 – 630) | 8.18 (6.87 – 9.68) | 1.04 (0.9 – 1.2) | 6.03 (4.59 – 7.75) |
| 11 – 20 | 117 | 234 (220 – 248) | 11.48 (10.85 – 12.12) | 1.8 (1.65 – 1.95) | 13.4 (11.92 – 14.87) | 134 | 335 (297 – 373) | 11.75 (10.93 – 12.56) | 2.13 (2.03 – 2.24) | 13.9 (12.69 – 15.11) |
| 21 – 40 | 68 | 136 (129 – 143) | 19.57 (17.24 – 22.16) | 4.74 (3.95 – 5.68) | 36.72 (29.04 – 46.29) | 48 | 120 (114 – 126) | 16.92 (14.13 – 20.11) | 2.63 (2.3 – 3) | 20.73 (16.58 – 25.67) |
| 41 – 60 | 17 | 34 (30 – 38) | 24.53 (21.2 – 28.25) | 3.24 (2.53 – 4.08) | 29.74 (22.24 – 39.1) | 7 | 18 (14 – 21) | 23.14 (17.98 – 29.07) | 1.51 (1 – 2.08) | 15.45 (9.20 – 22.89) |
| 61 – 80 | 11 | 22 (20 – 24) | 31.18 (26.99 – 35.87) | 3.75 (2.91 – 4.76) | 36.93 (27.61 – 48.55) | – | – | – | – | – |
| Total | 435 | 914 (852 – 976) | – | 14.49 (11.79 – 17.67) | 123.13 (95.38 – 157.38) | 432 | 1080 (1010 – 1150) | – | 7.32 (6.23 – 8.51) | 56.11 (43.06 – 71.41) |

**Table 4:** List of families, tree species composition and tree relative density in (a) lowland dipterocarp forest and (b) hill dipterocarp forest.

| a) Lowland dipterocarp forest | | | | | | b) Hill dipterocarp forest | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Family | No. of Genera | No. of Species | No of Stems | Relative density (%) | No. | Family | No. of Genera | No. of Species | No of Stems | Relative density (%) |
| 1 | Dipterocarpaceae | 6 | 26 | 114 | 26.21 | 1 | Euphorbiaceae | 8 | 13 | 119 | 27.48 |
| 2 | Euphorbiaceae | 8 | 13 | 114 | 26.21 | 2 | Dipterocarpaceae | 5 | 16 | 118 | 27.25 |
| 3 | Myrtaceae | 1 | 1 | 33 | 7.59 | 3 | Meliaceae | 1 | 2 | 28 | 6.47 |
| 4 | Lauraceae | 2 | 2 | 20 | 4.60 | 4 | Myrtaceae | 2 | 2 | 25 | 5.77 |
| 5 | Annonaceae | 4 | 5 | 18 | 4.14 | 5 | Lauraceae | 1 | 1 | 22 | 5.08 |
| 6 | Fagaceae | 1 | 1 | 15 | 3.45 | 6 | Sapotaceae | 1 | 1 | 17 | 3.93 |
| 7 | Myristicaceae | 2 | 2 | 15 | 3.45 | 7 | Fagaceae | 1 | 1 | 14 | 3.23 |
| 8 | Sapotaceae | 2 | 2 | 15 | 3.45 | 8 | Flacourtiaceae | 3 | 3 | 13 | 3.00 |
| 9 | Celastraceae | 1 | 1 | 12 | 2.76 | 9 | Annonaceae | 2 | 3 | 8 | 1.85 |
| 10 | Meliaceae | 1 | 2 | 11 | 2.53 | 10 | Tiliaceae | 1 | 2 | 8 | 1.85 |
| 11 | Tiliaceae | 2 | 2 | 11 | 2.53 | 11 | Myristicaceae | 1 | 1 | 7 | 1.62 |
| 12 | Burseraceae | 1 | 1 | 9 | 2.07 | 12 | Polygalaceae | 1 | 1 | 7 | 1.62 |
| 13 | Ebenaceae | 1 | 1 | 5 | 1.15 | 13 | Ebenaceae | 1 | 1 | 5 | 1.15 |
| 14 | Moraceae | 2 | 2 | 5 | 1.15 | 14 | Verbenaceae | 2 | 2 | 5 | 1.15 |
| 15 | Polygalaceae | 1 | 1 | 5 | 1.15 | 15 | Theaceae | 1 | 1 | 4 | 0.92 |
| 16 | Lecythidaceae | 1 | 1 | 4 | 0.92 | 16 | Anacardiaceae | 3 | 3 | 3 | 0.69 |
| 17 | Leguminosae | 2 | 2 | 4 | 0.92 | 17 | Bombacaceae | 1 | 2 | 3 | 0.69 |
| 18 | Anacardiaceae | 2 | 2 | 3 | 0.69 | 18 | Burseraceae | 1 | 1 | 3 | 0.69 |
| 19 | Bombacaceae | 1 | 1 | 3 | 0.69 | 19 | Leguminosae | 3 | 3 | 3 | 0.69 |
| 20 | Flacourtiaceae | 2 | 2 | 3 | 0.69 | 20 | Moraceae | 1 | 2 | 3 | 0.69 |
| 21 | Sterculiaceae | 1 | 2 | 3 | 0.69 | 21 | Symplocaceae | 1 | 1 | 3 | 0.69 |
| 22 | Alangiaceae | 1 | 1 | 2 | 0.46 | 22 | Dilleniaceae | 1 | 2 | 2 | 0.46 |
| 23 | Dilleniaceae | 1 | 2 | 2 | 0.46 | 23 | Sterculiaceae | 1 | 1 | 2 | 0.46 |

**Table 4:** (Continued)

| a) Lowland dipterocarp forest | | | | | | b) Hill dipterocarp forest | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Family | No. of Genera | No. of Species | No of Stems | Relative density (%) | No. | Family | No. of Genera | No. of Species | No of Stems | Relative density (%) |
| 24 | Guttiferae | 1 | 2 | 2 | 0.46 | 24 | Alangiaceae | 1 | 1 | 1 | 0.23 |
| 25 | Rubiaceae | 2 | 2 | 2 | 0.46 | 25 | Apocynaceae | 1 | 1 | 1 | 0.23 |
| 26 | Sapindaceae | 2 | 2 | 2 | 0.46 | 26 | Calophyllaceae | 1 | 1 | 1 | 0.23 |
| 27 | Erythroxylaceae | 1 | 1 | 1 | 0.23 | 27 | Erythroxylaceae | 1 | 1 | 1 | 0.23 |
| 28 | Magnoliaceae | 1 | 1 | 1 | 0.23 | 28 | Hypericaceae | 1 | 1 | 1 | 0.23 |
| 29 | Verbenaceae | 1 | 1 | 1 | 0.23 | 29 | Juglandaceae | 1 | 1 | 1 | 0.23 |
| | | | | | | 30 | Rubiaceae | 1 | 1 | 1 | 0.23 |
| | | | | | | 31 | Rutaceae | 1 | 1 | 1 | 0.23 |
| | | | | | | 32 | Sapindaceae | 1 | 1 | 1 | 0.23 |
| | | | | | | 33 | Thymelaeaceae | 1 | 1 | 1 | 0.23 |
| | | | | | | 34 | Ulmaceae | 1 | 1 | 1 | 0.23 |
| | | | | | | 35 | Ulmaceae | 1 | 1 | 1 | 0.23 |
| **Total** | | **54** | **84** | **435** | **100** | **Total** | | **55** | **77** | **434** | **100** |

**Table 5.** Shannon -Wiener Index and Shannon equitability with 95% CI by dbh range between forest types. The 95% CI was calculated for each dbh class and type of selectively logged forest separately.

| dbh classes (cm) | Lowland diptercoarp forest | | Hill dipterocarp forest | |
|---|---|---|---|---|
| | **Shannon's diversity index (H')** | **Shannon's equitability** | **Shannon's diversity index (H')** | **Shannon's equitability** |
| 5 - 10 | 3.45 (3.42 – 3.48) | 0.82 (0.82 – 0.83) | 3.19 (3.17 – 3.21) | 0.78 (0.77 – 0.78) |
| 11 - 20 | 2.92 (2.86 – 2.98) | 0.79 (0.78 – 0.81) | 2.53 (2.49 – 2.57) | 0.72 (0.71 – 0.73) |
| 21 - 40 | 1.74 (1.69 – 1.79) | 0.53 (0.52 – 0.55) | 1.66 (1.59 – 1.73) | 0.57 (0.54 – 0.59) |
| 41 - 60 | 1.07 (0.96 – 1.18) | 0.44 (0.39 – 0.48) | 0.60 (0.47 – 0.73) | 0.38 (0.29 – 0.46) |
| 61 - 80 | 0.54 (0.44 – 0.64) | 0.33 (0.27 – 0.39) | 0.07 (0.04 – 0.1) | 0.14 (0.07 – 0.21) |
| > 80 | 0.10 (0.05 – 0.15) | 0.22 (0.11 – 0.32) | – | – |

**Table 6**: List of species, species number of stems and importance value (IVI) between both selectively logged lowland dipterocarp forest and hill dipterocarp forest.

| Family/Species | | Lowland dipterocarp forest | | Hill dipterocarp forest | |
|---|---|---|---|---|---|
| | | No. of stems | IVI | No. of stems | IVI |
| 1 | Alangiaceae | | | | |
| 1. | *Alangium javanicum* | 2 | 1.31 (0.67 – 1.95) | 1 | 0.62 (0.62 – 0.62) |
| 2 | Anacardiaceae | | | | |
| 1. | *Campnosperma auriculatum* | 0 | – | 1 | 0.74 (0.74 – 0.74) |
| 2. | *Mangifera odorata* | 2 | 1.15 (0.59 – 1.71) | 1 | 0.58 (0.58 – 0.58) |
| 3. | *Parishia insignis* | 1 | 0.57 (0.57 – 0.57) | 1 | 0.58 (0.58 – 0.58) |
| 3 | Annonaceae | | | | |
| 1. | *Mezzetia leptopoda* | 6 | 2.84 (2.07 – 3.61) | 0 | – |
| 2. | *Orophea myriantha* | 1 | 0.54 (0.54 – 0.54) | 0 | – |
| 3. | *Polyalthia sumatrana* | 4 | 2.16 (1.37 – 2.95) | 1 | 0.65 (0.65 – 0.65) |
| 4. | *Xylopia ferruginia* | 2 | 1.22 (0.62 – 1.82) | 3 | 2.81 (1.58 – 4.03) |
| 5. | *Xylopia* spp. | 5 | 2.86 (1.96 – 3.76) | 4 | 2.44 (1.54 – 3.33) |
| 4 | Apocynaceae | | | | |
| *1.* | *Alstonia* spp. | 0 | – | 1 | 0.72 (0.72 – 0.72) |
| 5 | Bombacaceae | | | | |
| 1. | *Durio grandiflorus* | 3 | 1.71 (0.97 – 2.45) | 1 | 0.7 (0.7 – 0.7) |
| 2. | *Durio kutejensis* | 0 | – | 2 | 1.33 (0.68 – 1.98) |
| 6 | Burseraceae | | | | |
| 1. | *Canarium* spp. | 9 | 5.16 (4.16 – 6.16) | 3 | 1.9 (1.07 – 2.73) |
| 7 | Calophyllaceae | | | | |
| 1. | *Mesua borneensis* | 0 | – | 1 | 0.59 (0.59 – 0.59) |
| 8 | Celastraceae | | | | |
| 1. | *Kokoona ochracea* | 12 | 6.28 (5.34 – 7.22) | 0 | – |
| 9 | Dilleniaceae | | | | |
| 1. | *Dillenia borneensis* | 1 | 0.54 (0.54 – 0.54) | 1 | 0.58 (0.58 – 0.58) |
| 2. | *Dillenia excelsa* | 1 | 0.57 (0.57 – 0.57) | 1 | 2.6 (2.6 – 2.6) |
| 10 | Dipterocarpaceae | | | | |
| 1. | *Dipterocarpus acutangulus* | 13 | 10.43 (8.98 – 11.88) | 0 | – |
| 2. | *Dipterocarpus caudiferus* | 5 | 3.23 (2.22 – 4.24) | 6 | 2.14 (1.56 – 2.73) |
| 3. | *Dipterocarpus confertus* | 2 | 3.75 (1.91 – 5.59) | 0 | – |
| 4. | *Dipterocarpus* spp. | 4 | 2.49 (1.57 – 3.41) | 0 | – |
| 5. | *Dryobalanops lanceolata* | 7 | 5.87 (4.46 – 7.28) | 3 | 1.75 (0.99 – 2.51) |
| 6. | *Hopea nervosa* | 1 | 0.56 (0.56 – 0.56) | 0 | – |
| 7. | *Hopea sangal* | 0 | – | 3 | 1.45 (0.82 – 2.08) |

**Table 6**: (Continued)

| Family/Species | | Lowland dipterocarp forest | | Hill dipterocarp forest | |
|---|---|---|---|---|---|
| | | No. of stems | IVI | No. of stems | IVI |
| 9. | *Parashorea malaanonan* | 4 | 2.23 (1.41 – 3.05) | 0 | – |
| 10. | *Parashorea tomentella* | 3 | 2.24 (1.26 – 3.22) | 19 | 9.52 (8.59 – 10.45) |
| 11. | *Shorea agamii* | 0 | – | 1 | 0.99 (0.99 – 0.99) |
| 12. | *Shorea argentifolia* | 6 | 5.02 (3.65 – 6.39) | 0 | – |
| 13. | *Shorea atrinervosa* | 4 | 6.62 (4.19 – 9.05) | 1 | 3.63 (3.63 – 3.63) |
| 14. | *Shorea faguetiana* | 2 | 5.02 (2.56 – 7.48) | 0 | – |
| 15. | *Shorea falciferoides* | 0 | – | 2 | 19.22 (9.8 – 28.64) |
| 16. | *Shorea fallax* | 9 | 9.18 (7.4 – 10.96) | 15 | 4.23 (3.71 – 4.74) |
| 17. | *Shorea gibbosa* | 0 | – | 2 | 2.07 (1.06 – 3.09) |
| 18. | *Shorea johorensis* | 6 | 3.02 (2.2 – 3.84) | 0 | – |
| 19. | *Shorea leprosula* | 4 | 6.07 (3.84 – 8.3) | 8 | 8.32 (6.54 – 10.11) |
| 20. | *Shorea leptoderma* | 3 | 3.08 (1.74 – 4.42) | 0 | – |
| 21. | *Shorea macrophylla* | 0 | – | 24 | 11.09 (10.22 – 11.95) |
| 22. | *Shorea macroptera* | 19 | 13.9 (12.54 – 15.26) | 2 | 0.92 (0.47 – 1.37) |
| 23. | *Shorea ovalis* | 1 | 0.54 (0.54 – 0.54) | 6 | 7.34 (5.34 – 9.34) |
| 24. | *Shorea parvifolia* | 4 | 8.07 (5.1 – 11.04) | 19 | 9.8 (8.84 – 10.75) |
| 25. | *Shorea pauciflora* | 0 | – | 6 | 2.48 (1.8 – 3.15) |
| 26. | *Shorea pilosa* | 1 | 0.67 (0.67 – 0.67) | 0 | – |
| 27. | *Shorea pinanga* | 2 | 2.38 (1.21 – 3.55) | 0 | – |
| 28. | *Shorea seminis* | 1 | 1.03 (1.03 – 1.03) | 0 | – |
| 29. | *Shorea superba* | 2 | 1.8 (0.92 – 2.68) | 1 | 5.2 (5.2 – 5.2) |
| 30. | *Shorea symingtonii* | 1 | 1.26 (1.26 – 1.26) | 0 | – |
| 31. | *Shorea xanthophylla* | 6 | 2.53 (1.84 – 3.22) | 0 | – |
| 32. | *Vatica albiramis* | 5 | 2.83 (1.94 – 3.72) | 0 | – |
| 33. | *Vatica sarawakensis* | 1 | 0.64 (0.64 – 0.64) | 0 | – |
| 11 | Ebenaceae | | | | |
| 1. | *Diospyros macrophylla* | 5 | 2.86 (1.96 – 3.76) | 5 | 3.89 (2.67 – 5.11) |
| 12 | Erythroxylaceae | | | | |
| 1. | *Erythroxylum cuneatum* | 1 | 0.9 (0.9 – 0.9) | 1 | 1.19 (1.19 – 1.19) |
| 13 | Euphorbiaceae | | | | |
| 1. | *Aporusa elmeri* | 2 | 2.32 (1.19 – 3.46) | 2 | 1.21 (0.62 – 1.8) |
| 2. | *Aporusa grandistipula* | 0 | – | 2 | 1.33 (0.68 – 1.99) |
| 3. | *Baccaurea angulata* | 2 | 1.85 (0.94 – 2.76) | 0 | – |
| 4. | *Baccaurea lanceolata* | 2 | 1.87 (0.95 – 2.79) | 3 | 1.42 (0.8 – 2.04) |
| 5. | *Baccaurea parviflora* | 6 | 3.06 (2.23 – 3.89) | 3 | 13.47 (7.61 – 19.34) |
| 6. | *Blumeodendron tokbrai* | 4 | 1.35 (0.85 – 1.85) | 0 | – |
| 7. | *Endospermum diadenum* | 1 | 0.76 (0.76 – 0.76) | 2 | 6.45 (3.29 – 9.62) |

**Table 6**: (Continued)

| Family/Species | | Lowland dipterocarp forest | | Hill dipterocarp forest | |
|---|---|---|---|---|---|
| | | No. of stems | IVI | No. of stems | IVI |
| 9. | *Glochidion borneensis* | 5 | 1.86 (1.28 – 2.44) | 3 | 14.6 (8.24 – 20.95) |
| 10. | *Homalanthus populneus* | 0 | – | 3 | 1.04 (0.59 – 1.5) |
| 11. | *Koilodepas longifolium* | 19 | 8.04 (7.25 – 8.83) | 2 | 6.39 (3.26 – 9.52) |
| 12. | *Macaranga depressa* | 23 | 16.13 (14.82 – 17.44) | 57 | 16.13 (15.59 – 16.68) |
| 13. | *Macaranga gigantifolia* | 0 | – | 4 | 1.88 (1.19 – 2.58) |
| 14. | *Macaranga hypoleuca* | 19 | 12.08 (10.9 – 13.26) | 20 | 6.24 (5.66 – 6.82) |
| 15. | *Macaranga winkleri* | 1 | 0.55 (0.55 – 0.55) | 0 | – |
| 16. | *Mallotus mollissimus* | 0 | – | 1 | 1.75 (1.75 – 1.75) |
| 17. | *Mallotus* sp. | 28 | 13.98 (13.04 – 14.92) | 17 | 10.53 (9.38 – 11.67) |
| 18. | *Mallotus wrayi* | 2 | 1.13 (0.58 – 1.68) | 0 | – |
| 14 | Fagaceae | | | | |
| 1. | *Lithocarpus* spp. | 15 | 11.24 (9.87 – 12.61) | 14 | 4.75 (4.13 – 5.37) |
| 15 | Flacourtiaceae | | | | |
| 1. | *Homalium foetidum* | 0 | – | 8 | 5.51 (4.33 – 6.69) |
| 2. | *Hydnocarpus* spp. | 2 | 1.1 (0.56 – 1.64) | 1 | 0.59 (0.59 – 0.59) |
| 3. | *Ryparosa acuminata* | 1 | 0.56 (0.56 – 0.56) | 4 | 1.76 (1.11 – 2.4) |
| 16 | Guttiferae | | | | |
| 1. | *Garcinia mangostana* | 1 | 0.56 (0.56 – 0.56) | 0 | – |
| 2. | *Garcinia parvifolia* | 1 | 0.61 (0.61 – 0.61) | 0 | – |
| 17 | Hypericaceae | | | | |
| 1. | *Cratoxylum* spp. | 0 | – | 1 | 0.61 (0.61 – 0.61) |
| 18 | Juglandaceae | | | | |
| 1. | *Engelhardia serrata* | 0 | – | 1 | 0.69 (0.69 – 0.69) |
| 19 | Lauraceae | | | | |
| 1. | *Eusideroxilon zwageri* | 3 | 3.33 (1.88 – 4.78) | 0 | – |
| 2. | *Litsea* spp. | 17 | 12.29 (10.96 – 13.62) | 22 | 13.25 (12.12 – 14.38) |
| 20 | Lecythidaceae | | | | |
| 1. | *Barringtonia macrostachya* | 4 | 3.13 (1.98 – 4.28) | 0 | – |
| 21 | Leguminosae | | | | |
| 1. | *Crudia reticulata* | 3 | 1.69 (0.95 – 2.43) | 0 | – |
| 2. | *Koompassia excelsa* | 0 | – | 1 | 0.61 (0.61 – 0.61) |
| 3. | *Peltophorum racemosum* | 0 | – | 1 | 0.59 (0.59 – 0.59) |
| 4. | *Sindora beccariana* | 1 | 0.54 (0.54 – 0.54) | 1 | 0.71 (0.71 – 0.71) |
| 22 | Magnoliaceae | | | | |
| 1. | *Elmerrillia mollis* | 1 | 0.55 (0.55 – 0.55) | 0 | – |

**Table 6**: (Continued)

| Family/Species | | Lowland dipterocarp forest | | Hill dipterocarp forest | |
|---|---|---|---|---|---|
| | | No. of stems | IVI | No. of stems | IVI |
| 23 | Meliaceae | | | | |
| | 1. *Aglaia korthalsii* | 10 | 6.76 (5.57 – 7.95) | 27 | 13.7 (12.75 – 14.66) |
| | 2. *Aglaia odoratissima* | 1 | 0.57 (0.57 – 0.57) | 1 | 0.63 (0.63 – 0.63) |
| 24 | Moraceae | | | | |
| | 1. *Artocarpus anisophyllus* | 4 | 2.31 (1.46 – 3.16) | 2 | 1.59 (0.81 – 2.37) |
| | 2. *Artocarpus elasticus* | 0 | – | 1 | 0.71 (0.71 – 0.71) |
| | 3. *Ficus* spp. | 1 | 1.43 (1.43 – 1.43) | 0 | – |
| 25 | Myristicaceae | | | | |
| | 1. *Horsfieldia grandis* | 1 | 0.56 (0.56 – 0.56) | 0 | – |
| | 2. *Myristica iners* | 14 | 8.97 (7.8 – 10.14) | 7 | 6.85 (5.2 – 8.49) |
| 26 | Myrtaceae | | | | |
| | 1. *Eugenia* spp. | 33 | 20.4 (19.23 – 21.57) | 24 | 14.92 (13.75 – 16.09) |
| | 2. *Tristaniopsis merguensis* | 0 | – | 1 | 0.59 (0.59 – 0.59) |
| 27 | Polygalaceae | | | | |
| | 1. *Xanthophyllum ellipticum* | 5 | 3.17 (2.18 – 4.16) | 7 | 4.9 (3.72 – 6.08) |
| 28 | Rubiaceae | | | | |
| | 1. *Neolamarckia cadamba* | 1 | 1.18 (1.18 – 1.18) | 0 | – |
| | 2. *Neonauclea bernardoi* | 1 | 0.58 (0.58 – 0.58) | 1 | 0.62 (0.62 – 0.62) |
| 29 | Rutaceae | | | | |
| | 1. *Melicope luna-akenda* | 0 | – | 1 | 0.63 (0.63 – 0.63) |
| 30 | Sapindaceae | | | | |
| | 1. *Dimocarpus longan* | 1 | 0.61 (0.61 – 0.61) | 1 | 0.66 (0.66 – 0.66) |
| | 2. *Nephelium mutabile* | 1 | 0.54 (0.54 – 0.54) | 0 | – |
| 31 | Sapotaceae | | | | |
| | 1. *Mimusops elengi* | 1 | 0.57 (0.57 – 0.57) | 0 | – |
| | 2. *Palaquium* spp. | 14 | 6.71 (5.84 – 7.58) | 17 | 12.28 (10.95 – 13.61) |
| 32 | Sonneratiaceae | | | | |
| | 1. *Duabanga moluccana* | 0 | – | 1 | 4.01 (4.01 – 4.01) |
| 33 | Sterculiaceae | | | | |
| | 1. *Heritiera littoralis* | 1 | 0.57 (0.57 – 0.57) | 2 | 1.25 (0.64 – 1.86) |
| | 2. *Heritiera sumatrana* | 2 | 2.96 (1.51 – 4.41) | 0 | – |
| 34 | Symplocaceae | | | | |
| | 1. *Symplocos fasciculata* | 0 | – | 3 | 1.84 (1.04 – 2.64) |
| 35 | Theaceae | | | | |
| | 1. *Adinandra dumosa* | 0 | – | 4 | 2.34 (1.48 – 3.2) |
| 36 | Thymelaeaceae | | | | |
| | 1. *Aquilaria malaccensis* | 0 | – | 1 | 1.31 (1.31 – 1.31) |

**Table 6**: (Continued)

| Family/Species | | Lowland dipterocarp forest | | Hill dipterocarp forest | |
|---|---|---|---|---|---|
| | | No. of stems | IVI | No. of stems | IVI |
| 37 | Tiliaceae | | | | |
| | 1. *Microcos crassifolia* | 3 | 1.52 (0.86 – 2.18) | 0 | – |
| | 2. *Pentace adenophora* | 0 | – | 7 | 3.6 (2.73 – 4.46) |
| | 3. *Pentace laxiflora* | 8 | 4.17 (3.28 – 5.06) | 1 | 0.65 (0.65 – 0.65) |
| 38 | Ulmaceae | | | | |
| | 1. *Gironniera nervosa* | 0 | – | 1 | 0.62 (0.62 – 0.62) |
| 39 | Verbenaceae | | | | |
| | 1. *Geunsia pentandra* | 1 | 0.55 (0.55 – 0.55) | 1 | 1.4 (1.4 – 1.4) |
| | 2. *Vitex pubescens* | 0 | – | 4 | 1.29 (0.81 – 1.76) |
| | **Grand Total** | **437** | | **434** | |

## Discussion

This study revealed that after 14 years of recovery following logging, lowland and hill dipterocarp forest differed in terms of forest structure, tree carbon stocks and tree species composition.

### *Forest structure*

I found that tree density and tree basal area were significantly higher in lowland versus hill dipterocarp forest (Table 1). In most cases, differences were observed in the dbh of 21 – 40 cm dbh class and above, where the hill forest dipterocarp contained a lower tree density and tree basal area (Figure 3). Disappearance of trees above 80 cm dbh in hill dipterocarp may suggest that most of the large trees were extracted during logging and caused competitive release of small trees. I found that hill dipterocarp forest contained a higher tree density and higher tree basal area in dbh classes of 5 – 10 cm and 11 – 20 cm. Low density of trees above 40 cm dbh in hill dipterocarp forest compared to lowland dipterocarp forest may indicate that larger trees in hill dipterocarp forest were intensively extracted albeit selectively.

The results of the assessment for canopy heights were consistent with those of Richards (1952), who classified the classic view of dipterocarp forest with 5 (A – E) layering strata based on canopy height. Though, in terms of trees canopy, in this study I found that the dipterocarps were observed to have been dominating the canopy of the emergence stage. This is supported with my field assessment where four tallest trees were recorded in each subplot, some euphorbias present in emergent forests, but only adapted to a small forest gaps while most of the pioneer euphorbias could be outcompeted in canopy build up over time (Slik et al, 2003).

Heavily logged forest has more canopy gaps and light penetration which might have supported the growth of dipterocarp seedlings and saplings (Bebber *et al.,* 2002; Philipson *et al.*, 2011; Sasaki & Mori, 1981). Many studies have discovered that the status of logged forest in the tropics depends on many factors, including: disturbance of remnant forest stands, harvesting intensity, nutrient and soil types, landscapes and topography gradient (Alves *et al.*, 2010; Guariguata & Ostertag, 2001; Laumonier *et al.*, 2010; Sheil, 2001).

*Tree aboveground carbon (AGC) stocks*

The aboveground carbon stocks were higher in lowland dipterocarp forest compared to hill dipterocarp forest (Table 1). Both forest types contained higher tree aboveground carbon stocks at dbh size class of 21 – 40 cm and 41 – 60 cm (Figure 3c). I found that large trees contributed in a larger proportion to the amount of aboveground carbon stocks. This results was similar to the study of Slik *et al*. (2009) in Borneo who found that tree basal area was correlated with the aboveground biomass, which directly influenced the amount of carbon stocks but not the tree density.

My carbon estimates may led to have large error propagation due to the small size of the plots (Baker *et al.,* 2004, Chave *et al.,* 2004, Morel *et al.* 2011). However, I found comparable results of aboveground carbon stocks studies elsewhere in the Malaysian region, which varied across sites (Table 6). The differences across study sites were influenced by the diameter size, equation that used to calculate the biomass and conversion applied to estimate carbon stocks (Saner *et al.*, 2012). The comparison may suggest that logging intensity and number of years of recovery was the major influences to the amount of tree aboveground carbon stocks (Berry *et al.*, 2010; Pinard & Putz, 1996; Saner *et al.,* 2012; Tangki & Chappell, 2008).

*Vegetation and species diversity*

Most of the species encountered in this study were found commonly in both lowland and hill dipterocarp forest, as described by Whitmore *et al.,* (1990) and Meijer & Wood, (1964). Dipterocarpaceae and Euphorbiaceae were abundant and dominant in both forest types. Lowland dipterocarp forest contained a higher number of Dipterocarpaceae genera and species compared to hill dipterocarp forest. Hill dipterocarp forest comprised 35 trees families, 55 genera and 77 species. In contrast, lowland dipterocarp forest contained 29 trees families, 57 genera and 84 species (Table 2). The differences of tree composition among forest types might suggest that the intensity of logging and types of timber extracted during harvesting differed and influenced the damage of the residual forest during logging (Webb, 1997). Other studies have found that the natural recovery of seedlings in selectively logged forest was also influenced by habitat surrounding (Sukri *et al.*, 2011; Webb and Peart, 2000) and soil nutrient (Nilus *et al.*, 2011).

Hill dipterocarp forest had a higher family density then the lowland dipterocarp forest (Table 3). This may be typical but could suggest that continuous logging might cause losses of endemic species and favor pioneer species such as species of *Macaranga* spp. and *Mallotus* spp. Pioneer species were described to be abundant in logged forest also in a study by Slik *et al.* (2002): they found that the *Macaranga* spp sapling density was strongly correlated with both under and over-story density in the open canopy while the species was almost absent in the understory and common in the over-story of selectively logged forest.

The Shannon–Wiener Index and Shannon equitability indices indicated that trees of 5 – 10 cm dbh were more diverse than trees in other classes in both forest types (Table 4). In addition, higher tree density within 5 – 10 cm dbh size may suggest that selectively logged dipterocarp forests in lowland and hill take a long time to recover. In this case after only 14 years they can be considered to be at their early stages of natural recovery. The species of *Macaranga depressa* contributed the highest vegetation IVI in both forest types. Interestingly, the Dipterocarpaceae species of *Shorea macroptera* was observed among the dominant species in lowland dipterocarp forest but not in hill dipterocarp forest.

The differences of species diversity and vegetation IVI between lowland and hill dipterocarp forest may be due the intensity of logging activity in the past. Shannon diversity index has shown a declined correspondingly in lightly- and heavily-logged forests (Saiful, 2014). Thus, the Shannon index I estimated in this study also showed similarity in values with other study of 10 years selectively logged forest in Sungai Weng Catchment of Ulu Muda Forest Reserve, Kedah, Peninsular Malaysia (Saiful, 2014). In addition, the vegetation important value of the pioneer species *Macaranga depressa* was found to be among the highest in both forest types (Table 6) and the most common in hill dipterocarp forest. This may suggests that both forest types were disturbed and in the early stages of recovery where pioneer species are commonly observed (Slik *et al.,* 2002).

Surprisingly, I found that *Shorea macroptera* was among the most common and showed high IVI in hill dipterocarp forest. Even though, this species supposed to be found in lowland dipterocarp forest, none of S. *macroptera* found in the lowland dipterocarp forest plots in this study.

*Implication for forest management*

I found that lowland dipterocarp forest contained lower tree density but had higher tree basal area and tree aboveground carbon stocks compared to hill dipterocarp forest. Lowland dipterocarp forest comprised higher tree species diversity compared to hill dipterocarp forest. These attributes may suggest that restoration strategies should be differentiated according to the forest types. Furthermore, forest structure provided an importance description of the forest areas, which may support the strategies of logged forest management such as harvesting planning and logging techniques.

Dipterocarp species are mostly emergent species (Whitmore *et al.*, 1990), however, their seedlings and saplings grow well under the medium light intensity which commonly occurs in small forest gaps (Ashton, 1998; Meijer and Wood, 1964). In contrast, pioneers species such as *Macaranga* spp. need high light intensity, therefore they usually grow and become dominant in open canopies (Slik *et al.*, 2002). Consequently, pioneer species will limit the regeneration of Dipterocarpaceae species (Sist and Nguyen-Thé, 2002). However, my finding of high IVI of *Macaranga* spp. and *Mallotus* spp. in both forest types suggested that silviculture treatment such as thinning of pioneer species and enrichment planting of dipterocarps forest species can support the forest early recovery and enhance species diversity.

Many studies investigating the logged forest succession in tropical forests has discovered that species diversity, species richness and species composition may require decades or centuries to resemble mature forest (Bischoff *et al.,* 2005; Chazdon, 2003; Powers *et al.*, 2009). Remnants mature trees in logged forests serve as vital seed source for forest regeneration and are always affected by logging intensity and harvesting techniques (Okuda *et al.*, 2003; Pinard & Putz, 1996; Seng *et al.,* 2004). However, sustainable forest management through implementation of selective and systematic logging such as reduced impact logging (RIL) has supported the natural recovery compared to conventional logging (Bertault & Sist, 1997; Pinard & Putz, 1996; Sist & Bertault, 1998). A study by (Sist *et al.*, 2003) suggests that silviculture prescription such as spacing 35 – 50 m between harvested trees, determining the tree felling direction and maximum dbh limit for harvesting may improve the harvesting techniques and minimize the damage on the forest residual.

High vegetation importance values of pioneer species in both forest types suggest that proper forest management activities such as silviculture treatment may help accelerate forest recovery (Günter *et al.*, 2011). Furthermore, several studies discovered that restoration through enrichment planting in degraded forest may helps to restore the species richness and ecosystem functioning (Karam *et al.*, 2012; Mohamad Azani *et al*., 2011; Reynolds *et al.*, 2011).

**Conclusion**

This study highlighted the early forest recovery of 14 years selectively logged forest, which added knowledge on forest structure and tree aboveground carbon stocks of logged forest in lowland and hill dipterocarp forest. This study shows there are vast differences between the two forest types. In this study, I identified various areas where further research was needed: i) a more comprehensive review of the documents regarding the logging history in the study area, and ii) to compare selectively logged area with unlogged area in order to supports the implementation of sustainable forest management.

**Table 6:** Comparison of forest structure and tree aboveground carbon (AGC) stocks in this study with other selectively logged forest sites within Malaysian region.

| Location | [1] Forest type | Recent year of logging/disturbance | Tree basal area | Mean aboveground biomass (Mg ha-1) | [2] Estimated tree AGC stocks (Mg C ha-1) | Diameter limit (cm) | References |
|---|---|---|---|---|---|---|---|
| Commercial forest reserve at central Sabah, Borneo Malaysia | Lowland | 1995 | | 221.6 | 123.13 (95.38 – 157.38) | ≥ 5 cm | This study |
| | Hill | 1995 | | 130.2 | 56.11 (56.75 – 71.41) | | |
| Malua, Ulu Segama FR, Malaysia | Lowland | 1980 - 1990 | | 183.8 | 91.9 | > 10 cm | (Saner *et al.,* 2012) |
| Danum, Ulu Segama FR, Malaysia | Mixed Lowland and Hill | 1981 - 1992 | | 171.8 (36.2 – 307.4) | 85.9 (18.1 – 153.7) | ≥ 2cm | (Tangki and Chappell, 2008) |
| Ulu Segama Forest Reserve, Malaysia | Lowland | 1988-1989 | | 177 (148.2 – 205.8) | 88.5 (74.1 – 102.9) | ≥ 5 cm | (Berry *et al.*, 2010) |
| Pasoh, Malaysia | Lowland | 1958 | | 310 | 155 | ≥ 5 cm | (Okuda *et al.*, 2004) |
| Bukit Timah Natural Reserve, Singapore | Hill | 1950 | | 104.5 | 52.3 | ≥ 1 cm | (Ngo *et al.*, 2013) |
| Barito Ulu, Central Kalimantan, Indonesia | Lowland | 1942 - 1945 | | 358 | 179 | ≥ 10 cm | (Brearley *et al.*, 2004) |
| Sumatra, Indonesia | Hill | Old growth forest | | 360.6 | 180 | ≥ 10 cm | (Laumonier *et al.*, 2010) |

***Note:***

1 – Forest types:

- Lowland: Lowland dipterocarp forest
- Hill: Hill dipterocarp forest
- FR: Forest reserve

2 – Tree aboveground carbon stocks was estimated as 50% of the aboveground biomass.

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# Chapter 4

## Comparison of Forest Restoration Following Different Selective Logging Techniques Used in Sabah, Malaysian Borneo.

**Abstract**

The restoration of forest degraded by logging is important to restore carbon sequestration, maintain ecosystem functionality and ensure continued timber yield but little information is available on which species establish and grow best following different logging techniques. I studied a forest restoration project that uses indigenous species (mostly dipterocarps) to improve the recovery of degraded selectively logged forests. I assessed the survival and growth of enrichment-planted dipterocarp seedlings planted 21 year ago, comparing areas selectively logged by high lead and tractor yarding techniques. The species selected for this study were the dipterocarps *Dryobalanops lanceolata, Shorea leprosula, Shorea ovalis*, *Parashorea tomentella* and *Parashorea malaanonan.* The two *Parashorea* species were generally mixed within the same planting lines and were considered together as "*Parashorea* spp." with wood density reported as the average of the two species. The objective of the planting project was to rehabilitate selectively logged forest using enrichment line planting while monitoring the cost incurred by evaluating the performance (i.e. mortality and growth) of the planted seedlings. Aboveground carbon stocks of the enrichment planted species in the areas harvested using high lead machines and tractors were estimated after 21 years. The results suggest that enrichment planting has the potential to accelerate the recovery of carbon stocks. Growth rates were higher in the high lead logging area but within both areas the study species showed similar growth patterns to one another. All species suffered high mortality after 21 years, ranging from rates of 61% to 99%. However, in contrast to the growth patterns the overall mortality observed was slightly higher in the tractor logging sites compared to the high lead sites.

**Keywords:** Restoration, Enrichment line planting, Dipterocarp species, Growth, mortality and survival, High lead, Tractor, Selectively logged forest.

**Introduction**

Degradation of forests in Southeast Asia has increased during recent decades (Miettinen *et al.,* 2011; Gaveau *et al.,* 2014) which has decreased the capacity of the forests to support continued timber harvesting, but has also impacted the environmental and social functions associated with forests (Kobayashi, 2007). Timber harvesting using selective logging techniques is the most practiced method in Southeast Asia – but this technique still contributes significantly to forest damage with 40 - 70% damage to residual trees after logging (Fox, 1978).

In Sabah, from the mid-1960s, selective logging has used a combination of tractor yarding in areas of moderate terrain and high lead (cable) yarding on steeper slopes. Both techniques resulted in different forms of damage to the residual forest. The high lead logging technique involves winching logs up or down a slope to a stumping point around the machine, damaging an area of approximately 20 hectares, and often leaving a completely degraded area along the winching corridor. The tractor technique involves more random damage, ranging from highly degraded areas along skid tracks to lightly disturbed or undisturbed forest in the intervening areas. Tractor logging generally results in severe damage to between 10 and 40% of the area involved (Cannon *et al.,* 1993; Nussbaum *et al*., 1995a; Pinard *et al*., 1996). Enrichment planting is one of the most effective techniques in restoring degraded forest damaged by these types of selected logging (Lamb *et al.*, 2005).

Although many studies have been conducted to identify the best dipterocarp species to be reintroduced for the restoration of degraded logged forest, because rates of growth and mortality differ among species and in different post-logging situations matching of species to sites is not well understood (Bebber *et al.,* 2001; Brown and Lugo, 2009; Nilus *et al*., 2011; Philipson *et al.,* 2011; Pinard and Putz, 1996). Moreover, soil compaction, nutrient, and light conditions can strongly influence plant growth and mortality in the longer term in these sites but the effects of logging techniques on seedling growth and mortality have rarely been investigated, especially after more than 10 years following enrichment planting.

In this study, I assessed the growth, mortality and biomass stock for four dipterocarp species planted as part of the Innoprise-FACE Foundation Rehabilitation Project (INFAPRO) in Sabah. The objective of this study was to determine the performance of four dipetrocarp species 21 years after planting in forests degraded by high lead logging or/and tractor techniques. The specific study objectives were:

1) To evaluate dipterocarp mortality and growth rates after enrichment planting.
2) To evaluate the basal area and total aboveground carbon stored by the enrichment planted seedlings 21 years after planting
3) To evaluate the basal area, total aboveground carbon stocks and mortality rates of seedlings planted in sites logged using tractor and high lead techniques.

**Methodology**

**Study Area**

The INFAPRO project area consists of 25,000 ha of selectively logged dipterocarp forest in the Ulu Segama Forest Reserve (5° 00' N, 117° 30' E), one of the Forest Reserves making up the Sabah Foundation Concession area, in eastern Sabah, Malaysia (Figure 1). INFAPRO was implemented in forests that were logged between 1978 and 1991. The study area was logged in 1978, 1981, 1988 and 1991 on an annual coupe basis. Prior to logging, this forest was dominated by dipterocarps species (Fox, 1978, Newbery *et al*., 1992). The logged area is now mostly comprised of logged forests regenerating at different stages. The soils, geology and topography of this region are variable (Marsh and Greer, 1992). Mean annual rainfall is 2,800 mm with a mean annual temperature of 26.7$^{o}$C. Enrichment planting was carried out in 1993 and the first measurement was carried out after one year planting, in 1994.

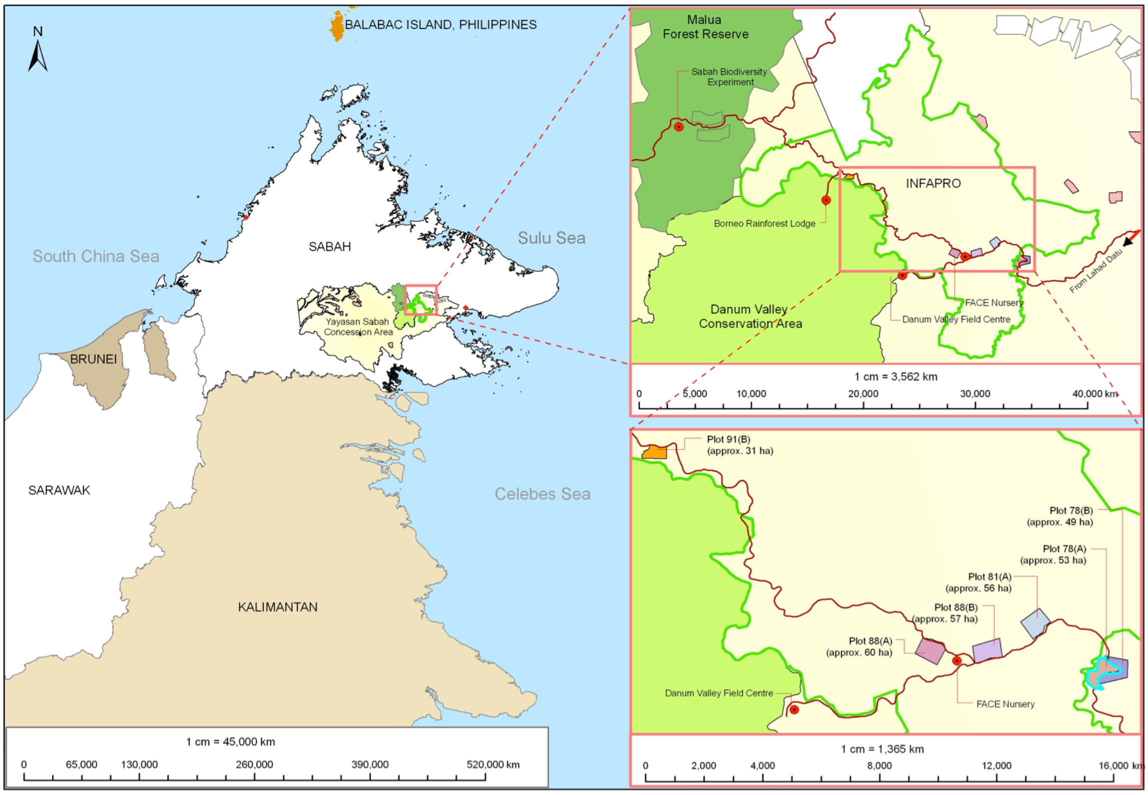


**Figure 1.** Location of the study area showing the experimental design

## Experimental design

As part of the rehabilitation of the selectively logged area, monitoring of some of the species performance was conducted in several "species trial" plots, in areas of both high lead logging and tractor logging techniques. I selected 6 replicate areas, 3 logged by high lead and 3 by tractor logging. Randomisation of logging techniques to areas was not possible as these areas were commercially logged between 1978 and 1991 and were not scientific projects with randomised blocked designs. As with all studies of commercial logging without randomised designs this brings the caveat of possible confounding of treatment and site effects (see discussion). However, I selected sites such that the treatments are spatially interspersed to minimise the risk of confounding. I also balanced the treatments with regard to age since logging as far as possible given what existed: one replicate of each logging type was logged in 1978 and a second of each in 1988 but the third replicate of the high lead technique was logged in 1981 whilst the third replicate of the tractor logging was logged a decade later in 1991, meaning there has been less time for recovery in the tractor logging area.

**Logging techniques and species trial**

High lead logging involves the use of steel cables and winches to drag logs to the log landing using a yarder that is set up at the landing site. In high lead logging, logs are attached directly to the end of the main winching line and can access timber at distances of up to a few hundred metres from the landing site. The logs cause severe damage as they are dragged across the forest floor. Tractor logging, which involves the use of heavy bulldozers, involves opening a path using the blade of the bulldozer. Logs are then dragged behind the bulldozer along skid trails to the landing site that is normally at the roadside or a flat area that can be used as a holding area.

Four species were chosen for this experiment from three genera of the Dipterocarpaceae family namely *Dryobalanops*, *Parashorea* and *Shorea* (Table 1; Appendix 3). Wood density used is given in Appendix 2.

**Table 1.** List of species and sample size for each logging technique.

| Family | Species | Treatment (logging technique) | |
|---|---|---|---|
| | | **High lead** | **Tractor** |
| *Dipterocarpaceae* | *Dryobalanops lanceolata* | 696 | 930 |
| | *Parashorea* spp. | 407 | 100 |
| | *Shorea leprosula* | 524 | 709 |
| | *Shorea ovalis* | 184 | 231 |
| | **Total** | **1,811** | **1,970** |

*Notes: Parashorea tomentella* and *Parashorea malaanonan* were mixed planted in the same line, thus was broadly named it *Parashorea* spp. and the wood density is given as the average.

**Site Preparation**

Maps, at a scale of 1:25,000, were utilized to facilitate site selection and planning of field activities. After the planting site had been selected, planting lines for the compartment were established by compassing. Cutting of vines and climbing bamboo were carried out six months prior to planting. Lining and 100% tagging of natural regeneration was then conducted before the transect line was established and opened.

For this study, six plots representing high lead logging (3 plots) and the tractor logging (3 plots) were selected (Table 2). Plots were numbered to represent the year when the plots were logged and given a letter indicating the type of logging technique implemented. For instance, plot 78A was logged in 1978 using high lead technique. The high lead logging plots were 78A (55 ha), 81A (55 ha) and 88A (56 ha). In 78A, 496 out of 18,351 planted seedlings were analysed; in 81A, 758 out of 17,991 planted seedlings were analysed and in 88A, 557 out of 17,991 planted seedlings were analysed. The tractor logging plots consisted of plots 78B (53 ha), 88B (52 ha) and 91B (29 ha). In 78B, 338 out of 14,217 planted seedlings were analysed; in 88B, 1,013 out of 16,267 planted seedlings were analysed and in 91B, 569 out of 8,173 planted seedlings were analysed.

**Planting system**

Spacing of the seedlings was adapted according to the crown-diameter/bole-diameter ratio. Enrichment planting lines are run into the selectively logged remnant vegetation in parallel lines at 10 m spacing and seedlings are planted every 3 m along each line in the centre of the 1 m wide line, providing a theoretical maximum planting density for the stand of 333 seedlings per hectare in flat areas (Figure 2). In practice, given that not all potential points can be planted (due to the presence of old logging roads, rivers, rocky and steep areas) the average planting density in the INFAPRO area is approximately 250 seedlings per ha (Reynolds, pers. com.).

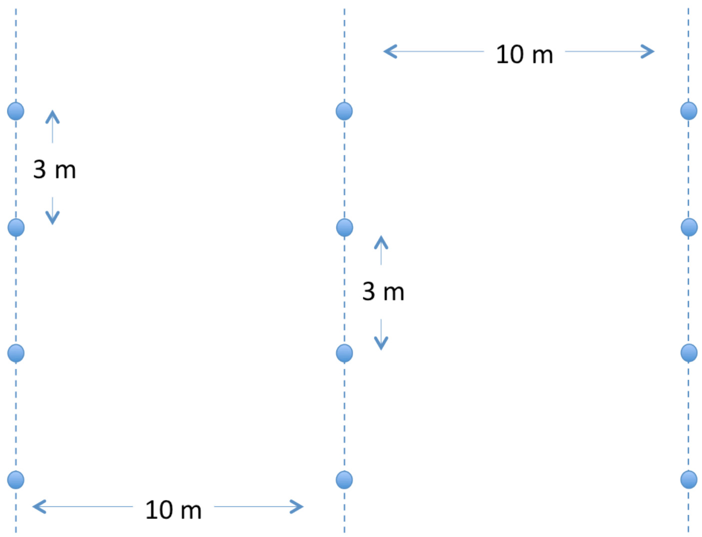


**Figure 2.** Schematic representation of enrichment line planting methods

**Table 2**. Description of the three replicate plots of each logging method. Plot numbering is based on the year of logging (1978 - 1991).

| Type of timber extraction | Plots | Area (ha) | General description | Slope range (%) | No. of seedlings planted *(analysed)* |
|---|---|---|---|---|---|
| High lead | 78A | 55 | Close canopy consisting predominantly of pioneer tree species, medium slopes. | 22 – 23 | 18,351 *(496)* |
| | 81A | 55 | Extremely open site, few remaining trees, presence of bamboos and bushy vegetation and grasses, gentle slopes. | 14 – 31 | 17,991 *(758)* |
| | 88A | 56 | Bushy vegetation, presence of grasses and lianas, open canopy and patches of dense vegetation, steep slopes. | 17 -28 | 17,539 *(557)* |
| **Total (High lead)** | | | | | **53,881** ***(1,811)*** |
| Tractor | 78B | 53 | Close canopy consisting predominantly of pioneer tree species, flat relief, lowland area in the margin of two rivers. | 0 – 2.5 | 14,217 *(338)* |
| | 88B | 52 | A combination of patches of undisturbed forest with dense canopy cover, and areas with scant vegetation, pioneer trees and lianas. | 3 – 12 | 16,267 *(1013)* |
| | 91B | 29 | Extremely disturbed site, presence of vines (mostly *Merremia*), need for intensive weeding, absence of canopy cover. | 15 – 18 | 8,173 *(569)* |
| **Total (Tractor)** | | | | | **38,657** ***(1,970)*** |

The seedlings of the various species were mixed along the planting lines. Tree species from natural regeneration were tagged along the lines and were recorded to facilitate site-species matching but were not included in the analysis or calculation of basal area or aboveground carbon. Prior to planting fertilizer (100 g rock phosphates) was added to the planting hole. Planting was conducted throughout the year but was halted if there were more than 3 consecutive days without rain. In the first three years, ground maintenance, such as climber cutting, weeding and slashing along the planting line was done every 3 months.

**Tree census**

Seedlings were planted in 1993 and inventories were conducted in 1994, 1999, 2002, 2006 and 2009 by Yayasan Sabah (the Sabah Foundation). The data from these inventories had not been fully processed and some were still on the paper recording sheets only. I therefore fully entered, checked, processed and archived the data for this PhD thesis. With financial support from FACE I also led the collection of a new survey in 2014 to measure the trees 21 years after planting. I measured Diameter at Breast Height (DBH) at 130 cm using standard DBH tapes and forestry callipers.

**Analysis**

All analyses were performed with the R statistical software version 2.15.0 (R Core Development Team 2012). I analysed mortality as a binary response (dead/alive) at any given date as well as the cumulate proportion that had died after 21 years. DBH was analysed as the relative growth rate (RGR) as described below. Binary data Generalized linear models (GLMs) with a binomial distribution and a logit link function were used to analyse the probability of seedling mortality at any given date. Relative Growth Rates can be calculated from the difference in the log transformed size between two surveys, or from the slope of a regression of size against time when there are more than two inventories (as here). I use General linear models (GLMs) with a log link function (the GLM equivalent to log transformation of the data) and a Gamma distribution to take account of the increasing variability to analyse the change in basal diameter over time. Due to the lack of a randomised blocked design, separate models were fitted for each species in each treatment and the resulting estimates and intervals informally compared. The mean total basal area and mean total of tree aboveground carbon at years 21 was also estimated using a General linear model (GLM) with a log link function and a Gamma distribution to model the increasing variance. Seedling mortality was analysed as binomial count data (number of alive ('successes') and dead ('failures') seedlings) using a binary GLM with a logistic link function and a binomial distribution.

The DBH measures were also used to calculate basal area, and to estimate aboveground biomass and carbon stocks. Carbon was estimated via total aboveground biomass using allometric linear regression equations from Basukiet al. (2009):

$$\ln(TAGB)=c+\alpha\ln(DBH)+ \beta\ln(WD)$$

where: TAGB is total aboveground biomass (Kg/tree); DBH is diameter breast height and WD is wood density (g cm$^{-3}$) of each plant species and the values of c (intercept), α (slope with DBH) and β (slope with wood density) are the corresponding regression coefficients that vary according to species group. Wood density values were taken from an agroforestry database (http://db.worldagroforestry.org/wd). When not available, the wood density values were taken from the most closely related species. After estimating aboveground biomass using the equation above, total aboveground carbon was taken as 50% of tree aboveground biomass ("The role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures," 1994).

## Results

*Mortality*

After 21 years the cumulative mortality was significantly lower (non-overlapping 95% CIs indicate $P<0.05$) in the high lead area for *D. lanceolata (61% vs. 79%)* and *Parashorea* spp. (*85% vs. 96%*). *S. ovalis* showed a significant difference in the opposite direction (99% vs. 89%) while *S. leprosula* showed no significant difference (Figure 4c; Appendix 1). *Dryobalanops* showed a lower mortality rate over all than the other three species.

*Dipterocarp growth rate*

All species grew significantly faster in high lead sites as compared to tractor logged sites (Figure 3; Appendix 1) with a basal diameter growth rate of 1.09 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.08 – 1.10) in *D. lanceolata*, 1.09 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.07 – 1.10) in *Parashorea* spp., 1.10 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.09 – 1.11) in *S. leprosula* and 1.10 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.06 – 1.14) in *S. ovalis*. Species within the tractor logging site grew similarly, but with lower basal diameter growth rate compared with seedlings growing in the high lead sites. *D. lanceolata* had a basal diameter growth rate of 1.03 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.02 – 1.04) and *Parashorea* spp. with a basal diameter growth rate of 1.05 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.00 – 1.011), *S. leprosula* with a basal diameter growth rate of 1.04 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.03 – 1.06) and *S. ovalis* with a basal diameter growth rate of 1.03 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.01 – 1.06).

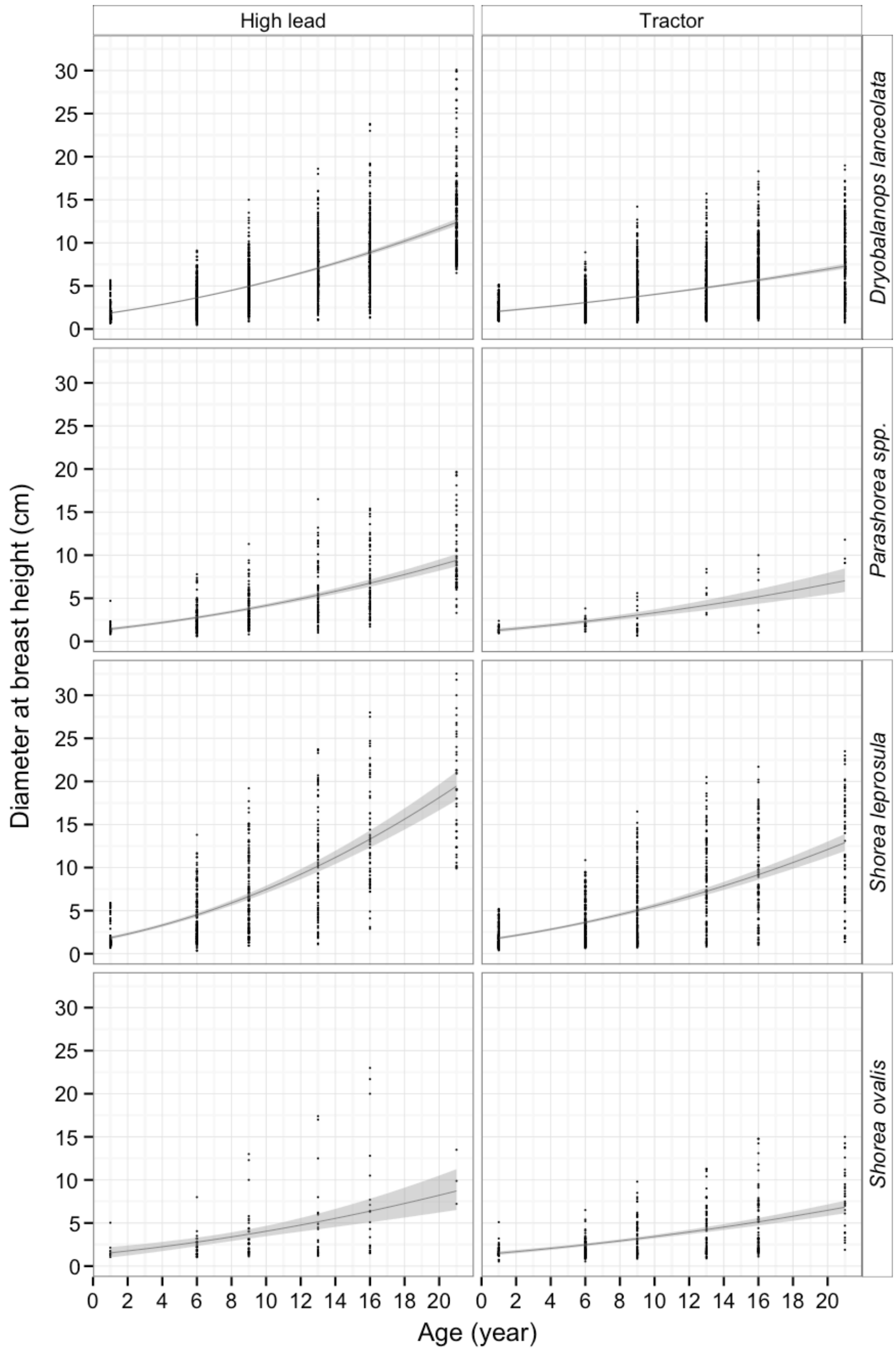


**Figure 3.** Seedling basal diameter through time for each treatment. The lines are regression curves of DBH vs. time for each species in each treatment from GLM analyses with a Gamma error distribution and natural log link. The grey bands indicate 95% confidence intervals for the curves.

*Stand basal area and aboveground carbon stocks*

Both the stand basal area mean and the tree aboveground carbon mean was greater in high lead sites compared to tractor logged sites (Figure 4). *S. leprosula* had the highest mean stand basal area in the high lead sites with 4.69 $m^2$ $ha^{-1}$ (95% CI: 3.89 – 5.61) and in the tractor logging sites with 3.21 $m^2$ $ha^{-1}$ (95% CI: 2.71 – 3.78). Some species had similar mean stand basal area values: *D. lanceolata* with 2.71 $m^2$ $ha^{-1}$ (95% CI: 2.51 – 2.91) and *Parashorea* spp. with 2.31 $m^2$ $ha^{-1}$ (95% CI: 1.67 – 3.05) in the high lead logging technique and also *D. lanceolata* with 1.92 $m^2$ $ha^{-1}$ (95% CI: 1.79 – 2.06) and *Parashorea* spp. with 1.70 $m^2$ $ha^{-1}$ (95% CI: 0.68 – 2.88) in the tractor logging technique (Figure 4a).

However there was a significant difference among species in mean aboveground carbon in both logging situations. *S. leprosula* had the highest mean aboveground carbon in both high lead and tractor sites with 9.71 mg $ha^{-1}$ (95% CI: 7.81 – 11.91) in the high lead site and with 6.20 mg $ha^{-1}$ (95% CI: 5.20 – 7.34) in the tractor logging site (Fig. 4b). *D. lanceolata* was the second highest in mean aboveground carbon in both high lead and tractor sites with 8.25 Mg $ha^{-1}$ (95% CI: 7.36 – 8.53) in the high lead logging sites and with 5.61 Mg $ha^{-1}$ (95% CI: 5.07 – 5.78) in the tractor logging sites (Figure 4b; Appendix 1).

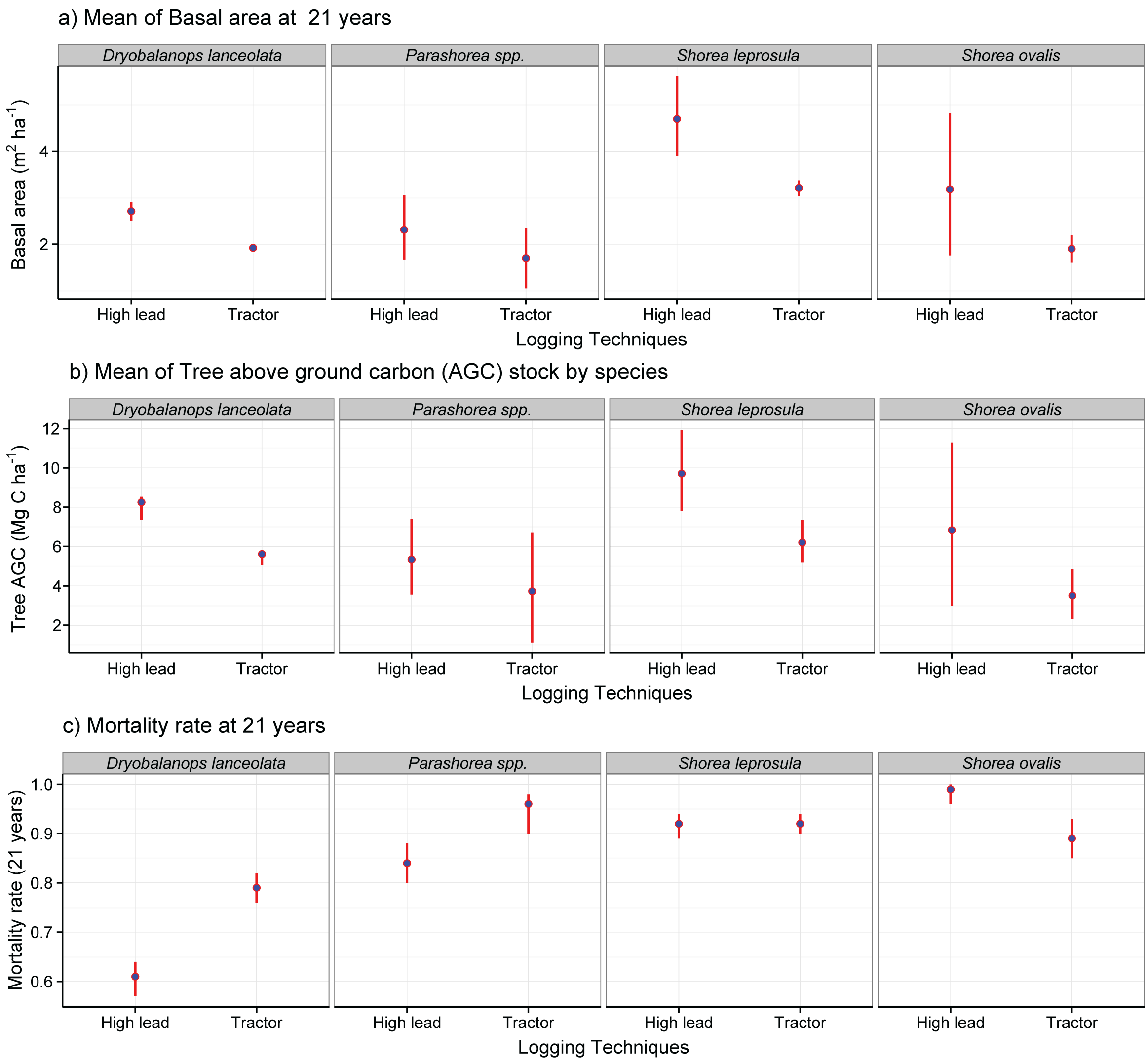


**Figure 4.** Basal area, aboveground carbon stock (enrichment planted trees only) and mortality rate at 21 years old. The red bands indicate the 95% confidence interval (back-transform from the glm model).

## Discussion

This study evaluated the survival and growth of seedlings of four dipterocarp species 21 years after enrichment planting, in areas previously logged using high lead or tractor techniques. I also assessed the effect on total basal area and aboveground carbon stocks achieved by enrichment planted seedlings. Mortality rates were generally high (60 to nearly 100%) with two species showing higher mortality in the high lead area, one in the tractor logged area and one uniformly high in both areas. However, growth was generally higher in the area logged using the high lead technique. After 21 years, the combined effects of mortality and growth resulted in greater tree basal area and greater tree aboveground carbon in the high lead logged areas for *Shorea leprosula* and *Dryobalanops lanceolata*. Interestingly the greater values in the high lead area for *Shorea leprosula* result from its fast growth rate (despite it also having the highest mortality rate) while Dryobalanops has one of the lower growth rates but high survival, especially in the high lead area. For the other two species there was no detectible difference in basal area and tree aboveground carbon stocks.

In this study, I found that the overall observed mortality was slightly higher in tractor logged sites as compared to high lead sites. In fact, all species suffered high mortality at 21 years ranging from 61% to 99% across all species. A similar result was observed in earlier studies, which reporting the mortality rates of planted trees (Nussbaum *et al.*, 1995b; Pinard *et al.*, 1999). It seems possible that these results may be due to the history of logging activities. When the forest is disturbed by logging, the soil is impacted in many ways (compaction, erosion, exposure to higher temperatures as a result of increased light inception at the forest floor. (Nussbaum *et al*., 1995b) reported that heating of the soil can lead to drastic changes in the nutrient cycle and rates of decomposition, leading to a reduction of organic matter in selectively logged forest compared with undisturbed rainforests. Noor and Smits (1988) found that the mortality of planted seedlings was due to high soil temperatures that in turn were correlated to different levels of canopy openness found in primary forest, secondary forest, strip plantations and open ground.

In addition, high mortality could also be due to the competition with pioneer species in the open conditions which are often present in degraded forest (King, 1994). Climbers could impact planted seedlings especially in their early stage development by competing with the planted seedlings not only for water and nutrients but also for light. Liew and Wong (1973) reported that seedlings overwhelmed by climbers and weeds frequently showed poor growth performance. (Fetcher *et al.,* 1985) reported that fast growing pioneers can establish shade and create a more humid microclimate under the shades than in the open area. Planted seedlings were also observed to compete among themselves for light, water and nutrients (Fox and Chai, 1982; Kuusipalo *et al.*, 1995). In tropical forests, plant growth normally depends on light availability (Denslow, 1980; Kitajima, 1994; Philipson *et al.,* 2011). (Philipson *et al.*, 2011) reported that growth increased, and mortality decreased, with increasing light availability.

Low survival rates, similar to those reported here have been reported for planted seedlings elsewhere (Tang and Wadley, 1976) with most seedling mortality occurring in plants less than 3 m tall (Wyatt-Smith *et al.,* 1963). A lack of information on patterns of mortality, and changes in seedling density, over time is a shortcoming of this analysis that would have provided useful information on stand development. I noted that other causes of mortality were mammalian browsers (Wyatt-Smith *et al.,* 1963), and dipterocarp seedlings were susceptible to damage by insect borers during early establishment (Smits *et al.,* 1991). During the tree census, I also found severe termite attack to the roots and stems of both small and big trees, and in both living and dead trees. This also in accordance with earlier observations (Wilcken *et al.,* 2002), which found that termites are among the root-boring species in many tropical and sub-tropical regions.

There are, however, other possible explanations for the observed tree growth and mortality. According to Smits (1983), dipterocarps are naturally associated with ectomycorrhizal fungi, which play an important role in the successful establishment and survival of seedlings. After logging, the soil is exposed to full sunlight that can destroy the ectomycorrhizal fungi (Lee and Lim, 1989). With the possible reduction in ectomycorrhizal fungi, the survival of seedlings can be affected.

Mortality could also have been due to the droughts that occurred in Sabah in the years 1994 and 1997– 98 (Walsh and Newbery, 1999) through the physiological stress caused by drought (Awang & Sawal, 1986). A study of the growth and mortality of seven shade-tolerant trees, including two dipterocarp species, showed a significant increase in seedlings mortality and height loss during the severe drought in the first three months of 1998 in the Lambir Hills National Park on the north-west coast of Borneo by (Delissio and Primack, 2003). (O'Brien *et al.,* 2014), reported that mortality increases during the rainless periods.

I found that the mean diameter growth in the INFAPRO project was slightly lower compared to the similar approach of enrichment line planting in the unrecorded logging activities in the past in Tapah Forest Reserve, Perak (K. Abd Rahman, 2008). For two species growth was faster in the high lead area but the opposite pattern was observed for a third species while a fourth showed no difference. Although the difference in annual RGR appears only small it can produce large differences after 21 years of growth and these differences may become more pronounced in the future given the 60 year cutting cycle anticipated for enrichment planted sites.

The weaknesses in the randomized block design and the quality of the data collected constrained statistical interpretation and hence the conclusions drawn.

The initial objective of the planting project was to rehabilitate the selectively logged forest using enrichment line planting and to evaluate the performance (i.e. mortality and growth) of the planted seedlings. The results of this study suggest that enrichment planting using *D. lanceolata*, *Parashorea* spp*., S. leprosula* and *S. ovalis* have the potential to accelerate the recovery of carbon stocks, although many species struggled to survive under the conditions at both sites. In future, I recommend similar studies to be repeated with a more robust experimental designs, the inclusion of more environmental variables and improved data collection methods in order to better test growth, aboveground carbon stocks and mortality rates of species in areas of different selective logging techniques.

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**Appendix I**

Species group performance based on the RGR of Diameter at breast height and tree aboveground carbon stocks relative growth rate, basal area and total of tree aboveground carbon at 21 years old planted trees, and cumulative mortality rates ($year^{-1}$) by treatment and total aboveground carbon of 16 year old planted trees.

| | | | |
|---|---|---|---|
| a) | **A) Relative growth rates of Diameter at breast height (dbh) cm $cm^{-1}$ $year^{-1}$ (95% CI)** | | |
| | Species | High lead | Tractor |
| | *Dryobalanops lanceolata* | 1.10 (1.09 – 1.10) | 1.07 (1.06 – 1.07) |
| | *Parashorea* spp. | 1.10 (1.08 – 1.11) | 1.10 (1.07 – 1.13) |
| | *Shorea leprosula* | 1.13 (1.12 – 1.15) | 1.11 (1.09 – 1.12) |
| | *Shorea ovalis* | 1.10 (1.07 – 1.13) | 1.08 (1.07 – 1.10) |
| b) | Average basal area at 21 years old planted trees in Basal $M^2$ $ha^{-1}$ (95% CI) | | |
| | Species | High lead | Tractor |
| | *Dryobalanops lanceolata* | 2.71 (2.51 – 2.91) | 1.92 (1.79 – 2.06) |
| | *Parashorea* spp. | 2.31 (1.67 – 3.05) | 1.70 (0.68 – 2.88) |
| | *Shorea leprosula* | 4.69 (3.89 – 5.61) | 3.21 (2.71 – 3.78) |
| | *Shorea ovalis* | 3.18 (1.76 – 4.83) | 1.90 (1.39 – 2.49) |
| c) | Average tree aboveground carbon at 21 years old planted trees in Mg $ha^{-1}$ (95% CI) | | |
| | Species | High lead | Tractor |
| | *Dryobalanops lanceolata* | 8.25 (7.36 – 8.53) | 5.61 (5.07 – 5.78) |
| | *Parashorea* spp. | 5.34 (3.57 – 7.39) | 3.73 (1.13 – 6.69) |
| | *Shorea leprosula* | 9.71 (7.81 – 11.91) | 6.20 (5.20 – 7.34) |
| | *Shorea ovalis* | 6.83 (2.99 – 11.29) | 3.51 (2.32 – 4.87) |
| d) | Mortality at year 21 in percentage (95% CI) | | |
| | **Species** | High lead | Tractor |
| | *Dryobalanops lanceolata* | 61 (57 – 64) | 79 (72 – 85) |
| | *Parashorea* spp. | 85 (78 – 90) | 96 (83 – 99) |
| | *Shorea leprosula* | 92 (88 – 95) | 92 (78 – 98) |
| | *Shorea ovalis* | 99 (96 – 100) | 89 (85 – 93) |

**Appendix 2**

Overview of the species trial: Species identified to species or genus level. Wood Density: From the World Agroforestry Centre, Tree Functional Attributes and Ecological Wood Density Database (http://db.worldagroforestry.org/wd/species). BA: mean (95% Confidence interval) basal area, DBH: diameter at breast height.

| Treatment/ Species | Planted | | | Survival | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of trees | Size of area (ha) | Density ($ha^{-1}$) | Total of survival tree | Survival (%) | Density ($ha^{-1}$) | BA ($m^2$ $ha^{-1}$) | DBH range (cm) | Wood Density | AGC (Mg C $ha^{-1}$) |
| **High lead** | | | | | | | | | | |
| *Dryobalanops lanceolata* | 696 | 2.09 | 128 | 274 | 39.37 | 50 | **3.98 (3.59 – 4.42)** | 6.50 – 30.10 | **0.70** | **12.43 (11.09 – 13.99)** |
| *Parashorea* spp. | 407 | 1.22 | 75 | 62 | 15.23 | 11 | **0.55 (0.45 – 0.69)** | 4.9 – 19.68 | **0.49** | **1.36 (1.07 – 1.76)** |
| *Shorea leprosula* | 524 | 1.57 | 96 | 41 | 7.82 | 8 | **1.29 (1.00 – 1.71)** | 9.9 – 32.50 | **0.47** | **2.93 (2.21 – 4.00)** |
| *Shorea ovalis* | 184 | 0.55 | 34 | 2 | 1.09 | 0 | **0.02 (0.01 – 0.06)** | 7.22 – 9.88 | **0.52** | **0.02 (0.01 – 0.12)** |
| **Total** | **1811** | **5.44** | **333** | **379** | **63.51** | **70** | **12.90 (9.84 – 16.41)** | | | **30.13 (21.73 – 53.79)** |

Notes: AGC = aboveground carbon, BA = basal area

**Appendix 2.** Continued

| Treatment/ Species | Planted | | | Survival | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No. of trees | Size of area (ha) | Density (ha$^{-1}$) | Total of survival tree | Survival (%) | Density (ha$^{-1}$) | BA (m$^2$ ha$^{-1}$) | DBH range (cm) | Wood Density | AGC (Mg C ha$^{-1}$) |
| **Tractor** | | | | | | | | | | |
| *Dryobalanops lanceolata* | 930 | 2.79 | 157 | 194 | 20.86 | 33 | **1.05 (0.95 – 1.17)** | 5.2 – 18.98 | **0.70** | **4.48 (4.06 – 4.95)** |
| *Parashorea* spp. | 100 | 0.3 | 17 | 4 | 4 | 1 | **0.03 (0.01 – 0.09)** | 9.10 – 11.80 | **0.49** | **0.07 (0.04 – 0.16)** |
| *Shorea leprosula* | 709 | 2.13 | 120 | 55 | 7.76 | 9 | **0.78 (0.63 – 0.99)** | 5.90 – 23.50 | **0.47** | **1.97 (1.64 – 2.39)** |
| *Shorea ovalis* | 231 | 0.69 | 39 | 23 | 9.96 | 4 | **0.14 (0.10 – 0.21)** | 6.10 – 15.60 | **0.52** | **0.35 (0.26 – 0.47)** |
| **Total** | **1970** | **6** | **333** | **276** | **47** | **47** | **8.73 (6.57 – 11.21)** | | | **19.05 (13.72 – 24.68)** |

Notes: AGC = aboveground carbon, BA = basal area

**Appendix 3**

Ecology of studied species after described by Meijer and Wood (1964) and Newmanet al. (1996, 1998).

| **Species (local name)** | **Wood density** | **Ecology** | **Description** |
|---|---|---|---|
| *Dryobalanops lanceolata* Bruck<br><br>***Dryobalanops lanceolata* Burck,** (Kapur paji) | Heavy hardwood | • Distributed up to 700 m altitude, hillsides and ridges with sandy soils.<br>• In undisturbed mixed dipterocarp forests up to 400 m altitude. On hillsides and ridges with sandy soils.<br>• In secondary forests usually present as a pre-disturbance remnant tree.<br><br>**Distribution:** Borneo (Sarawak, Brunei, Sabah, East-Kalimantan). | Emergent trees up to 69 m tall and 230 cm dbh. Stem with resin. Stipules up to ca. 12 mm long. Leaves alternate, simple, penni-veined, rather narrow and long, secondary veins placed close together. Flowers ca. 14 mm in diameter, white-yellow, placed in panicles. Fruit ca. 15 mm long, green-yellow-red, with five up to ca. 90 mm long wings placed on top of the calyx cup, wind dispersed.<br><br>**Uses:** Timber is used. Resin is used as fuel and anti infectant. |
| *Parashorea* spp. | Light hardwood | Distributed below 200 m altitude, on flat and undulating land with fertile clay soils. | The vernacular name for this species is Urat Mata. It can be found from east coast of North Borneo and adjacent Indonesian Borneo. It is commonly found at flat or slightly undulating land just above sea level, moderately well drained meandering streams or area subject to occasional flooding and on altitude less than 150 m. It is said that this species has almost similar characteristic with *P. malaanonan* except the leaves of *P. tomentella* are larger and its mature leaves are covered with close pale fulvous, stellate tomentum. |

**Appendix 3.** Continued.

| | | |
|---|---|---|
| | | *Parashorea* trees have hard wood, can reach heights exceeding 70 metres, and have limbs reaching outward over ten metres. |
| *Shores leprosula* Miq. (Seraya tembaga) | The vernacular name for this species is Seraya Tembaga. It can be found from north Peninsular Thai throughout Peninsular Malaysia and Sumatra to Borneo. It is commonly found on low well drained or swampy soil in the lowland and hill Dipterocarp forests up to about 450 m a.s.l in North Borneo. | The bole is fissured with elliptical leaves, which are yellow-tomentosa on the lower surface. *S. leprosula is* a large tree reaching 60 m. in height and frequently exceeding 3 m. in girth. The bole is grey-brown coloured, tall and well shaped. The crown is wide, umbrella shaped with light copper colour. The buttress is prominent and usually not very large. |
| *Shorea ovalis* Korth. *(*Seraya kepong) | In undisturbed mixed dipterocarp forests up to 700 m altitude. Usually on hillsides and ridges, rarely alluvial. Mostly on (coarse) sandy to clayey soils. In secondary forests usually present as a pre-disturbance remnant tree. | Upper canopy tree up to 49 m tall and 138 cm dbh. Stem with resin. Stipules up to ca. 13 mm long. Leaves alternate, simple, penni-veined, very narrow and elongate, petiole and lower surface scaly, feeling like sand paper. Flowers ca. 12 mm in diameter, white-yellow, placed in panicles. Fruits ca. 12 mm long, reddish, with three ca. 78 mm long wings, wind dispersed.<br><br>Uses The timber is used.<br><br>Distribution :<br><br>Peninsular Malaysia, Sumatra, Borneo (Sarawak, Brunei, Sabah, West-, Central-, South- and East-Kalimantan) |

**Appendix 4**

Total aboveground carbon (TAGC) stocks in logged and unlogged forest from several studies. TAGC with 95% CI either given by the author or was calculated from the given standard error (SE) or standard deviation (SD) of their study. TAGC without 95% CI due to no information given by the author. The `status´ column is referring to the study site where; (a) unlogged forest, (b) logged forest, (a.a) unlogged alluvial forest, (a.m) unlogged moist forest, (b.hl) logged forest using high lead technique, (b.t) logged forest using tractor technique, (b.ld) logged forest in lowland dipterocarp, (b.hd) logged forest in hill dipterocarp. The (*) is referring to this study with enrichment planting, (**) and (***) is referring to other chapters in this dissertation. TAGB stands for total aboveground biomass and AGC stands for aboveground carbon.

| Authors | Year | Status | Basal | TAGC | TAGB | Forest status | Place | Notes |
|---|---|---|---|---|---|---|---|---|
| *Godoong, 2014 (This study) | 2014 | b.hl | 12.9 (11.86 – 13.93) | 30.08 (21.45 – 39.32) (tree AGC) | 55.6 (50.28 – 60.92) | Selectively logged | Danum | Enrichment line planting (Lowland Forest) |
| *Godoong, 2014 (This study) | 2014 | b.t | 8.73 (6.57 – 11.21) | 19.05 (13.72 – 24.68) | 34.86 (29.74 – 39.98) | Selectively logged | Danum | Enrichment line planting (Lowland Forest) |
| **Godoong, 2014 (Study from other chapter) | 2014 | b.ld | 31.23 (30.88 – 31.57) | 107.49 (105.92 – 109.06) | 242.42 (236.8 – 248.06) | Selectively logged | Imbak Canyon | Natural regeneration forest (Lowland Forest) |
| **Godoong, 2014 (Study from other chapter) | 2014 | b.hd | 19.92 (19.76 – 20.08) | 61.52 (60.13 – 62.9) | 146.26 (142.62 – 150.12) | Selectively logged | Imbak Canyon | Natural regeneration forest (Hill dipterocarps) |
| ***Godoong, 2014 (Study from other chapter) | 2014 | b.LF | 29.84 (29.82 – 29.86) | 98.35 (98.25 – 98.45) | 196.7 (196.5 – 196.9) | Selectively logged | Crocker Range Park (CRP) | Natural regeneration forest (Lowland Forest) |

**Appendix 4.** Continued.

| Authors | Year | Status | Basal | TAGC | TAGB | Forest status | Place | Notes |
|---|---|---|---|---|---|---|---|---|
| ***Godoong, 2014 (Study from other chapter) | 2014 | b.LM | 20.58 (20.37 – 20.79) | 70.68 (70.58 – 70.78) | 141.36 (141.17 – 141.56) | Selectively logged | Crocker Range Park (CRP) | Natural regeneration forest (Lower montane) |
| Hamzah Tangki, 2014 | 2014 | b1 | 15.96 | 52.98 (34.04 – 81.59) | 105.96 (68.08 – 163.18) | Selectively logged | Ulu Segama. Forest Reserve Tawau | Natural regeneration forest (Lowlaforest) |
| Hamzah Tangki, 2014 | 2014 | b2 | 9.11 | 28.53 (20.93 – 38.89) | 57.06 (41.86 – 77.78) | Selectively logged | BentaWawasan Tawau | Natural regeneration forest (Lowlaforest) |
| (Ngo *et al.,* 2013) | 2013 | b | NA | 104.52 | 209.04 | Selectively logged | Singapore | Natural regeneration forest (Lowlaforest) |
| (Saner *et al.*, 2012) | 2012 | b | NA | 91.9 (86.1 –97.7) | 183.8 (172.2 – 195.4) | Selectively logged | Malua | Natural regeneration forest (Lowlaforest) |
| (Neto *et al.*, 2012) | 2012 | b | NA | 81.17 | 162.33 | Selectively logged | Ayer Hitam | Natural regeneration forest (Lowlaforest) |
| (Morel *et al.*, 2011) | 2011 | b1 | NA | 123.83 (101.83 – 124.05) | 247.67 (203.67 – 248.11) | Selectively logged | Malua | Natural regeneration forest (Lowlaforest) |

**Appendix 4.** Continued.

| Authors | Year | Status | Basal | TAGC | TAGB | Forest status | Place | Notes |
|---|---|---|---|---|---|---|---|---|
| (Morel et al., 2011) | 2011 | b2 | NA | 126.3 (120.1 – 132.5) | 252.6 (240.2 – 265) | Selectively logged | Deramak ot | Natural regeneration forest |
| (Piyaphongkul *et al*., 2011) | 2011 | b | NA | 99.1 | 198.2 | Selectively logged | Thailand | Natural regeneration forest |
| (Berry *et al.,* 2010) | 2010 | b | NA | 88.5 (74.1 – 102.9) | 177 (148.2 – 205.8) | Selectively logged | Asia | Natural regeneration forest |
| (Tangki and Chappell, 2008) | 2008 | b | NA | 85.9 (18.1 – 153.7) | 171.8 (36.2 – 307.4) | Selectively logged | Danum | Natural regeneration forest |
| (Pinard and Putz, 1996) | 1996 | b | NA | 73.5 (54.3 – 92.7) | 147 (108.6 – 185.4) | Selectively logged | Ulu Segama Sabah | Natural regeneration forest |
| (Paquette *et al.,* 2009) | 2009 | b | NA | 56.5 | 113 | Selectively logged | Panama | Natural regeneration forest |
| *** Godoong, 2014_alf | 2014 | a.LF | 44.53 (44.52 – 44.54) | 169.76 (169.7 – 169.82) | 339.52 (339.4 – 339.64) | Unlogged | Crocker Range Park (CRP) | (Lowland forest) |
| *** Godoong, 2014_alm | 2014 | a.LM | 35.01 (34.96 – 35.05) | 124.21 (124.03 – 124.39) | 248.42 (248.06 – 248.78) | Unlogged | Crocker Range Park (CRP) | (Lower montane) |

**Appendix 4.** Continued.

| Authors | Year | Status | Basal | TAGC | TAGB | Forest status | Place | Notes |
|---|---|---|---|---|---|---|---|---|
| *** Godoong, 2014_aum | 2014 | a.UM | 29.17 (29.16 – 29.17) | 101.34 (101.3 – 101.38) | 202.68 (202.61 – 202.75) | Unlogged | Crocker Range Park (CRP) | (Upper montane) |
| Hamzah_*et_al*_2014_a | 2014 | a | 29.53 | 114.08 | 228.16 | Unlogged | Maliau Basin | (Lowland forest) |
| (Ngo *et al.,* 2013) | 2013 | a | NA | 167.49 | 334.98 | Unlogged | Singapore | (Lowland forest) |
| (Saner *et al.*, 2012) | 2012 | a | NA | 128 (101.2 – 154.8) | 256 (202.4 – 309.6) | Unlogged | Danum Valley | (Lowland forest) |
| (Piyaphongkul et al., 2011) | 2011 | a | NA | 342 | 684 | Unlogged | Thailand | - |
| (Berry *et al.*, 2010) | 2010 | a | NA | 138 (109 – 167) | 276 (218 – 334) | Unlogged | Danum Valley | (Lowland forest) |
| (Niiyama *et al.*, 2010) | 2010 | a | NA | 268 (267 – 269) | 536 (534 – 538) | Unlogged | Pasoh Forest Reserve | (Lowland forest) |
| (Tangki and Chappell, 2008) | 2008 | a | NA | 253.2 (193 – 313.4) | 506.4 (386 – 626.8) | Unlogged | Danum Valley | (Lowland forest) |
| (Terakunpisut *et al.*, 2007) | 2007 | a | NA | 137.73 | 275.46 | Unlogged | Thailand | - |

**Appendix 4.** Continued.

| Authors | Year | Status | Basal | TAGC | TAGB | Forest status | Place | Notes |
|---|---|---|---|---|---|---|---|---|
| (Feeley *et al.*, 2007) | 2007 | a | NA | 247.5 | 495 | Unlogged | Pasoh Forest Reserve | (Lowland forest) |
| (Lasco et al., 2006; Lasco and Pulhin, 2009) | 2006 | a | NA | 170.28 | 340.56 | Unlogged | Surigao Philiphines | - |
| (Okuda *et al.*, 2003) | 2003 | a1 | NA | 155 | 310 | Unlogged | Pasoh Forest Reserve | (Lowland forest) |
| (Okuda *et al.*, 2003) | 2003 | a2 | NA | 138 | 276 | Unlogged | Pasoh Forest Reserve | (Lowland forest) |
| (Kitayama and Aiba, 2002) | 2002 | a | NA | 133 | 266 | Unlogged | Mt. Kinabalu | (Montane forest) |
| (Clark *et al.,* 2001) | 2001 | a | NA | 107.75 | 215.5 | Unlogged | Pasoh Forest Reserve | (Lowland forest) |
| (Pinard and Putz, 1996) | 1996 | a | NA | 166.8 (133.6 – 200) | 333.6 (267.2 – 400) | Unlogged | Ulu Segama Sabah | (Lowland forest) |
| (Putz and Pinard, 1993) | 1993 | a | NA | 200 | 400 | Unlogged | Sabah | (Lowland forest) |

**Appendix 4.** Continued.

| Authors | Year | Status | Basal | TAGC | TAGB | Forest status | Place | Notes |
|---|---|---|---|---|---|---|---|---|
| (Brown et al., 1993) | 1993 | a.m | NA | 112.5 | 225 | Unlogged | Moist Forest South East Asia | - |
| (Brown et al., 1993) | 1993 | a | NA | 171.25 | 342.5 | Unlogged | Sarawak | (Lowland forest) |
| (Yamakura *et al.*, 1986) | 1986 | a | NA | 254 | 508 | Unlogged | Indonesia | - |
| (Proctor *et al*., 1983) | 1983 | a.a | NA | 115 | 230 | Unlogged | Sarawak | (Lowland forest) |
| (Proctor *et al*., 1983) | 1983 | a | NA | 325 | 650 | Unlogged | Sarawak | (Lowland forest) |
| (Brown and Lugo, 1982) | 1982 | a | NA | 167.75 | 335.5 | Unlogged | Tropical forest | - |

# Chapter 5

## Early Development of Ten Indigenous Tree Species Used for Forest Restoration in Borneo, Sabah, Malaysia.

**Abstract**

Dipterocarp forest restoration using indigenous species has been successfully implemented in several countries in Southeast Asia. Identifying the appropriate species and planting methods are important to the success of forest restoration projects. This study examined the performance of nine Dipterocarpaceae and one Lauraceae species planted using three different approaches on degraded land within the campus of Universiti Malaysia Sabah. The species studied are nine dipterocarps; *Dryobalanops lanceolata, Hopea sangal, Parashorea tomentella, Shorea argentifolia, S. fallax, S. macroptera, S. parvifolia, S. smithiana, Vatica albiramis* and one Lauraceae; *Eusideroxylon zwageri.* I estimated growth and mortality rates among species planted under three treatments: i) enrichment line planting in a degraded forest area (all species), ii) open line planting in an area of open slope dominated by the non-native grass *Imperata cylindrica* (two species) and iii) dense grid planting under girdled *Acacia mangium* trees (four species). Only one species (*D. lanceolata*) was grown under all three treatments and three other species in two treatments. The lack of a fully randomized blocked design and imbalance in species occurrence in different treatments limited my analyses to within-site in most cases. I present separate analyses for each species in each treatment and limit my self to a subjective comparison of treatments with the caveat of potential confounding effects of site. *D. lanceolata* was amongst the faster growing species in all three situations with a mean basal diameter growth rate of 1.05 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.03 – 1.06) in the enrichment line planting site, 1.38 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.32 – 1.44) in the open line planting site and 1.56 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.47 – 1.66) in the dense grid planting site. There was no mortality of *D. lanceolata* in the enrichment line planting site, 2% in the open line planting site, and 20% in the dense planting treatment area. *E. zwageri* had excellent early performance with a basal diameter growth rate of 1.58 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.50 – 1.67) in the open line

planting site and a basal diameter growth rate of 1.09 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.07 – 1.10) in the enrichment line planting site with zero mortality in both cases. Subject to the caveats due to the constraints of the study design, *E. zwageri* grew best in the open line planting site and *D. lanceolata* grew best in the dense grid planting area. Mortality rates were generally low and the growth rates were lowest overall in the enrichment line planting treatment. Although the lack of a randomized block design limits the strength of my conclusions, this study suggests that, in contrast to current opinion, with suitable planting medium adequate nutrients and systematic maintenance, indigenous tree species grow well in full sun light, even in an area dominated by the invasive grass *I. cylindrica*.

**Keywords:** Forest restoration, Dipterocarp species, Growth, Mortality and survival, Urban degraded land.

**Introduction**

Land degradation in tropical rainforest has been on the increase. Kobayashi (2004) reported that tropical forests are being cleared at a rate of 16.9 million hectares per year, and logging has resulted in over 5 million hectares becoming secondary forests annually. In Southeast Asia, logging activity and conversion to oil palm plantation are the two major causes of forest destruction (Flint, 1994, Sodhi *et al.,* 2004; Miettinen *et al.,* 2011). Malaysia has been listed as one of the 14 major countries experiencing the highest rate of deforestation at 250,000 ha (Wood, 1990). For example, between 1966 and 1985, the loss of forest to logging was about 74,000 ha per year (FAO, 1987). About 75% of Borneo was still forested in 1973 but only about half of the island's area is now forest (Gaveau *et al.*, 2014).

The dynamics of tropical rainforest regeneration involves a very complex interaction due to its habitat associations (Webb & Peart, 2000) and spatial heterogeneity (Beckage & Clark, 2003). In Southeast Asia, enrichment planting in selectively logged forest has shown potential to increase seedling densities and an important step towards sustainable management of degraded tropical forests (Whitmore, 1975). Bebber *et al.* (2002) emphasized that enrichment planting with commercially important indigenous tree species, particularly dipterocarps, is necessary to sustain timber production of selectively logged tropical rain forests. According to Panayotou & Ashton (1992), however, the success of enrichment planting varies vastly with the methods used. It depends on a wide range of factors including site conditions, species characteristics, planting techniques, management treatmentsas well as social and economic factors (Evans, 1996).

In Malaysia, enrichment planting with dipterocarp species has been implemented since 1949 (Appanah & Weinland, 1993) and is being widely applied to restore degraded areas. Several studies have been conducted to understand the details of the planting methods and species interactions (Chan *et al.,* 2008; Bebber *et al.,* 2002; Hector *et al.,* 2011). Line planting is a common technique where seedlings are planted along cleared lines. This method is known as enrichment planting in the Peninsular Malaysia Forest Department's forest rehabilitation operations (Appanah & Weinland, 1993).

In the state of Sabah, large scale enrichment planting has been carried out by Yayasan Sabah through the Innoprise-FACE Foundation Rainforest Rehabilitation Project (INFAPRO) to rehabilitate 25,000 ha of selectively logged dipterocarp forest at Ulu Segama Forest Reserve in Lahad Datu District (Moura-Costa *et al.,* 1994). A similar project, the Innoprise-IKEA Rehabilitation Project (INIKEA) is rehabilitating 18,500 ha of logged-over lowland dipterocarp forest at Kalabakan Forest Reserve in Kalabakan District, by enrichment planting using dipterocarp and fruit trees (Garcia & Falck, 2003). Furthermore, the Sabah Forestry Department is implementing large-scale enrichment planting at the Ulu Segama Forest Reserve involving 250,000 hectares (Sabah Forest Department, 2008).

Another technique to rehabilitate the degraded forest in Bintulu, Sarawak, Malaysia is the dense planting described by Miyawaki (1993). This method involves dense planting of mixed dipterocarp species in plots and uses organic materials (mulching using rice straw) to improve the soil (Miyawaki, 1993). Assessment by Miyawaki (1993) and Said (1993) reported that after one year, the average survival rate of dipterocarp species was around 89%. Two or three years after planting, weeding was implemented and the dead weeds were used as mulch for the saplings. Three years after planting, the sapling crown was developed, which reduced the sunlight to the soil surface and no further maintenance was required (Miyawaki 1993).

In many of the enrichment projects and studies using dipterocarp species in Sabah, high variability in growth performance has been observed (Lugo, 1998; Whitmore & Brown, 1996; Bebber *et al.,* 2002). Varying degrees of soil compaction are usually the result of repeated passes by the heavy crawler tractors during timber extraction (Garcia & Falck, 2003; Pinard *et al.,* 2000). The logging activities also contribute to canopy gaps (Bebber *et al.,* 2002) and alter the stand composition (Shono *et al.,* 2006; Romell *et al.,* 2008), which in turn affect seedling mortality and growth rates.

This paper reports the seedling growth performance of nine species of Dipterocarpaceae and one Lauraceae in rehabilitation sites on degraded lands in Sabah. The species range from light to heavy hardwood species and are common in primary mixed lowland dipterocarp forest (Table 1). The characteristics of the studied species are described by Meijer & Wood (1964) and Newman *et al. (*1996, 1998). The study evaluates the growth performance of one-year-old seedlings planted on degraded land within an urban area (rehabilitation sites on degraded lands around city areas) with three different planting treatments. Although the replanting exercise does not have a randomized block design the data on the survival and growth of the different species in the different areas may nevertheless be of interest (with the appropriate caveats) to projects conducting forest restoration in urban areas.

**Materials And Methods**

**Study site**

This study was conducted on the campus of Universiti Malaysia Sabah (UMS), Kota Kinabalu, Sabah, Malaysia 6°00' N, 116°04' E (Figure 1). The site is located in Bukit UMS (UMS Hills), 5 km from the city of Kota Kinabalu. The average annual mean temperature ranged from 26 to 34°C. The total rainfall received was 2,400 mm per year. UMS Hills has undulating terrain across about 75% of its area. The slope ranges between 5° and 45° and the soils are mostly porous and fertile. Some areas have bare soil and are infertile, which include exposed horizontally stratified sedimentary rocks and very thin soil because of the disturbance from the heavy machinery use during road and building construction. The most degraded area was dominated by ferns and the grass *Imperata cylindrica*. Pioneers such as *Macaranga* spp. and *Mallotus* spp. were abundant within the regenerating forest. Planted trees, saplings and seedlings of *Acacia mangium* were scattered on the hillsides and ridge tops. Rubber trees (*Hevea brasiliensis*) aged from 10 to 15 years were also found in areas leading to the Sepanggar Bay boundary, planted by the villagers before the area was gazetted to the management of UMS.

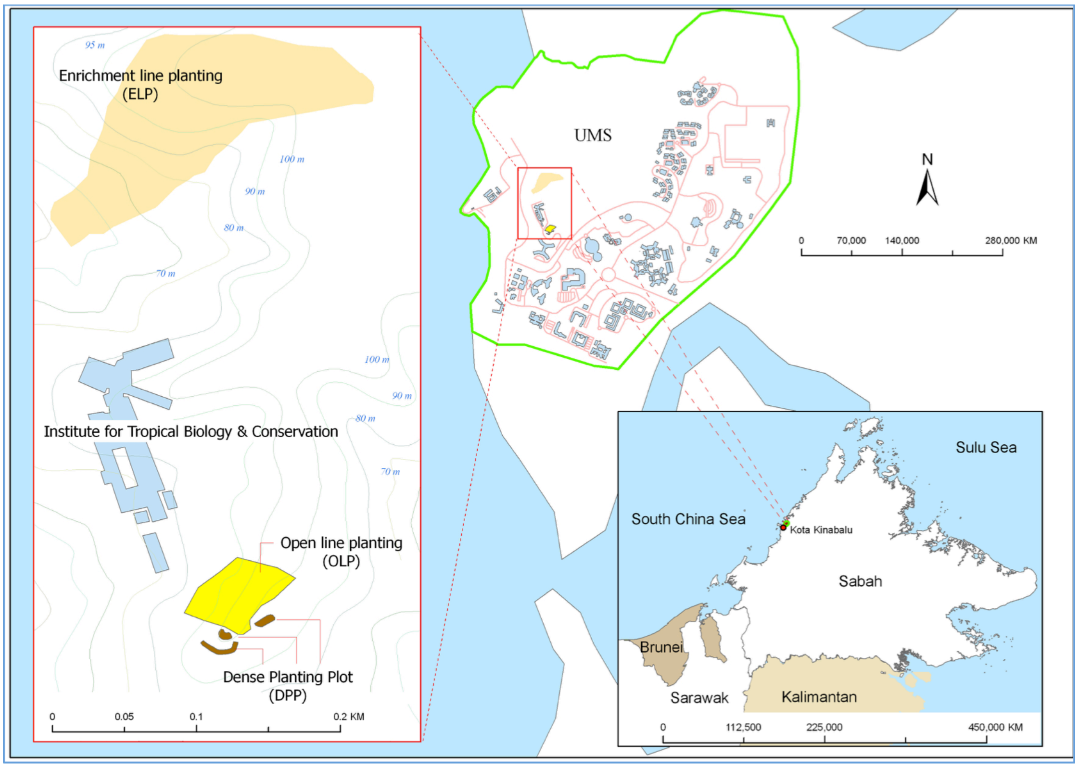


**Figure 1.** Location of the study area showing the experimental design.

**Table 1.** Ecology of studied species after described by Meijer and Wood (1964) and Newman *et al. (*1996, 1998).

| Species | Wood density | Habitat |
|---|---|---|
| *Dryobalanops lanceolata* Bruck | Heavy hardwood | Distributed up to 700 m altitude, hillsides and ridges with sandy soils. |
| *Eurodoxylon zwageri* Teijsm. & Binn. | Heavy hardwood | Distributed up to 600 m altitude, along rivers and adjacent hills with well-drained soils and sandy to clay-loam. |
| *Hopea sangal* Korth | Medium hardwood | Distributed up to 500 m altitude, adjacent hills with well-drained soils and sandy soil. |
| *Parashorea tomentella* (Symington) Meijer | Light hardwood | Distributed below 200 m altitude, on flat and undulating land with fertile clay soils. |
| *Shorea argentifolia* Symington | Light hardwood | Distributed on undulating land at altitudes between 500 and 1200 m with well-rained soil. |
| *Shorea fallax* Meijer | Light hardwood | Distributed up to 1000 m altitude with alluvial sites to dry hillside and ridge. |
| *Shorea macroptera* Dyer | Light hardwood | Distributed up to 600 m altitude with sandy clay soil. |
| *Shorea parvifolia* Dyer | Light hardwood | Distributed up to 1000 m altitude, alluvial (swamps and riversides) and dry (hillside and ridges) sites with clay to sand soils. |
| *Shorea smithiana* Symington | Light hardwood | Distributed up to 600 m altitude, ridge and hillside with sandy soils. |
| *Vatica albiramis* Slooten | Medium hardwood | Distributed up to 1000 m altitude at the flat to hillside with sand clay soil. |

**Experimental design**

This study was set up in conjunction with the UMS Hills rehabilitation project, which commenced on the 22nd of May (2010) A total of 2,400 seedlings aged four years old were planted comprising 16 species of dipterocarp and non-dipterocarp (Appendix I). Planting was divided into two phases involving 1,418 seedlings and 933 seedlings planted during Phase 1 and Phase 2, respectively. Phase 2 started one year after Phase 1, in May 2011 and was excluded from this study. Phase 1 applied three planting treatments, namely the enrichment line planting, dense grid planting and open line planting in the open area (Table 2). The planting treatments varied in plot size, habitat characteristics, seedling species, number of species planted and the planting medium (Table 2). The different planting treatments were not combined in a single randomized block design but have been applied in separate areas. Therefore, the analysis for each treatment was carried out separately and the results compared qualitatively with the caveat that treatment effects may be confounded with site effects due to differences in soil type moisture, slope, etc. Repeat studies using randomised block designs to avoid the confounding of treatment with site effects will be necessary to confirm the results reported here.

**Enrichment Line Planting (ELP)**

The enrichment line planting was done in an area of regenerating forest, which consisted of mixed non-dipterocarp tree species. A 3 x 3 m spacing between seedlings was used (Figure 2a). Planting medium from a mixture of humus and topsoil was used to provide high nutrients for the early root establishment. The standard size of planting holes was 0.5 $m^3$.

**Table 2.** Descriptions of experiment design, planting site and species planted at three different treatment areas.

| Planting treatment | No. of plots | Planting methods | Topography | Vegetation cover description | Species selected | No of seedlings |
|---|---|---|---|---|---|---|
| Enrichment line planting (ELP)<br>- in the mixed regenerated degraded forest | 3 | Line spacing is 3 x 3 m with 0.5 x 0.5 x 0.5 m planting medium | Undulating slope | Mixed species trees of regenerated selectively logged forest | *Dryobalanops lanceolata* | 247 |
| | | | | | *Eurodoxylon zwageri* | 409 |
| | | | | | *Hopea sangal* | 55 |
| | | | | | *Parashorea tomentella* | 19 |
| | | | | | *Shorea argentifolia* | 20 |
| | | | | | *Shorea fallax* | 22 |
| | | | | | *Shorea macroptera* | 18 |
| | | | | | *Shorea parvifolia* | 11 |
| | | | | | *Shorea smithiana* | 69 |
| | | | | | *Vatica albiramis* | 67 |
| Open line planting (OLP)<br>- in the open area<br>- dominated by *Imperata cylindrica* | 1 | As in enrichment line planting but in open slope area | Undulating slope | Dominated by the grass of *Imperata cylindrica* and no standing trees. | *Dryobalanops lanceolata* | 100 |
| | | | | | *Eurodoxylon zwageri* | 51 |
| Dense grid planting girdled (DGP)<br>- within girdled *Acacia mangium* | 3 | Dense grid planting | Flat to gentle slope within some steep areas | *Acacia mangium* trees have been girdling. | *Dryobalanops lanceolata* | 41 |
| | | | | | *Hopea sanga* | 20 |
| | | | | | *Shorea fallax* | 75 |
| | | | | | *Shorea smithiana* | 105 |
| | | | | | *Eurodoxylon zwageri* | 51 |

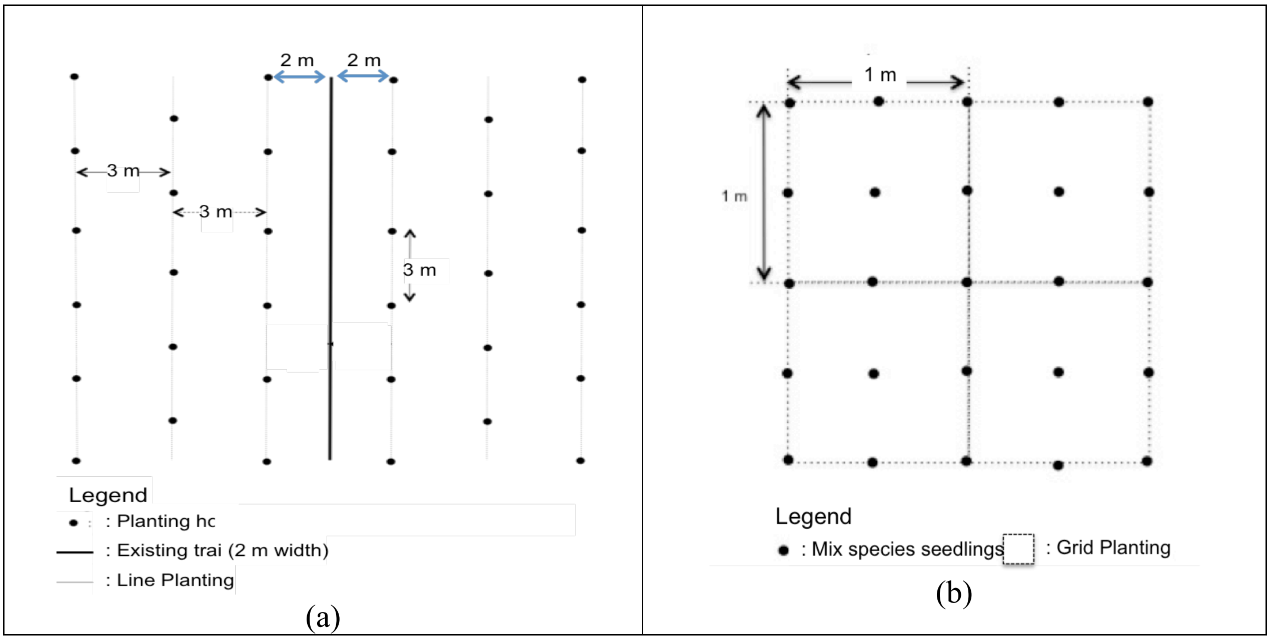


**Figure 2.** Schematic of planting methods of seedlings: (a) line planting and (b) dense grid planting

**Open Line Planting**

The open line planting treatment was located in an open area with a steep slope (between 20$^{o}$ and 45$^{o}$). The area was terraced and disturbed by heavy machinery. The planting area was dominated by *Imperata cylindrica* (L.) grass with no trees present. *I. cylindrica* has been reported as a pest by 73 countries, and is listed as one of the top 10 worst weeds in the world (Holm *et al.,* 1977). The planting methods and planting medium as applied in enrichment line planting were used. Prior to planting, the site of open line planting was slashed to trim the *I. cylindrica.* The grass cutting and weeding maintenance was carried out all over the plot every two months to control the *I. cylindrica* and other weeds. The leaf litter was stacked around the seedling or between the planting lines as mulch material. For the first six months after planting, all seedlings were watered if there were two or more continuous days of hot and rainless weather.

**Dense Grid Planting (DGP)**

The dense grid planting treatment had four planting beds. *Acacia mangium* trees dominated the planting area. The method applied was a modification of the "Miyawaki method" (Miyawaki, 1993). Planting beds were established under the shade of *A. mangium*. An average of five individual seedlings were planted per square meter (Figure 2b). Planting medium was prepared by mixing coconut husk powder with topsoil. The rice straw and coconut husk were used to retain soil moisture and prevent weeds. A tree girdling process was implemented on some of the *A. mangium* trees during the site preparation, a few days before the planting. Tree girdling is a slow process of killing the standing trees by removing the outer and inner bark from the main trunk without using herbicide (Heiligmann, 1998). The girdled *A. mangium* trees provide temporary shade to the seedlings. In the first six months after planting, all seedlings were watered if there were two or more continuous days of hot and rainless weather.

**Data collection**

Overall 1,418 seedlings comprising 20 species were measured within the three different treatments. The variables measured were the basal diameter at 10 cm above the ground level, bole height and total height of each seedling. The diameter at breast height was measured of seedlings taller than 1.3 m. Seedling damage was observed and recorded. The response variables were measured on the planting day and then repeated at six months (183 days) and one year (360 days) after planting.

**Species selection**

Ten out of the 20 species planted were selected for my study based on a minimum of ten individual seedlings per species for a given treatment. The selected species are

*Dryobalanops lanceolata, Hopea sangal, Parashorea tomentella, Shorea argentifolia, S. fallax, S. macroptera, S. parvifolia, S. smithiana, Vatica albiramis* and *Eusideroxylon zwageri.* The number of species analysed differed in each treatment: ten species in enrichment line planting, two species in open line planting and four species in dense grid planting (Table 2).

**Analysis**

I performed a separate analysis for each species in each treatment to assess the relative growth rate (RGR), probability of seedling mortality and percentage survival rate using R version 2.15.0 (R Core Development Team 2012). I used a linear model to compare species differences in basal diameter growth through time, analyzing the log-transformed seedling sizes as a function of time using the three planting dates. . Generalized linear models with a binomial error distribution and logit link function were used to estimate the probability of seedling mortality, with alive or dead as the binary response variable and species as explanatory variable.

**Results**

**Enrichment Line Planting (ELP)**

**Figure 3** and **Table 3** present the seedling growth rates for each species in each treatment. In the enrichment line planting area, growth rates varied from a low of 0.88 (95% CI: 0.83 – 0.95) for *Parashorea tomentella* to *Vatica albiramis* with the highest RGR of 1.12 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.09 – 1.15). *Dryobalanops lanceolata* had the highest RGR in the dense grid planting area with growth of 1.56 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.47 – 1.66), performing much better than in the other two treatment areas. *Eusideroxylon zwageri* in the open line planting area showed the highest growth rate of any species-treatment combination, with a basal diameter growth rate of 1.58 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.50 – 1.67).

The estimated seedling mortality rate of each species in the different treatments was generally very low. **Table 4** shows the highest cumulative mortality observed for *Hopea sangal* (6%) in the enrichment line planting treatment area, and for *Dryobalanops lanceolata* (2%) in open line planting and *D. lanceolata* (22%) in dense grid planting treatment. In the enrichment line planting treatment, *Hopea sangal* was the only species with less than 100 % survival. *Dryobalanops lanceolata* survival rate was excellent (100%) in enrichment line planting followed by open line planting treatment (98%) and lower in dense grid planting treatment (78%). *Eusideroxylon zwageri* had 100 % survival rate in dense grid planting and open line planting.

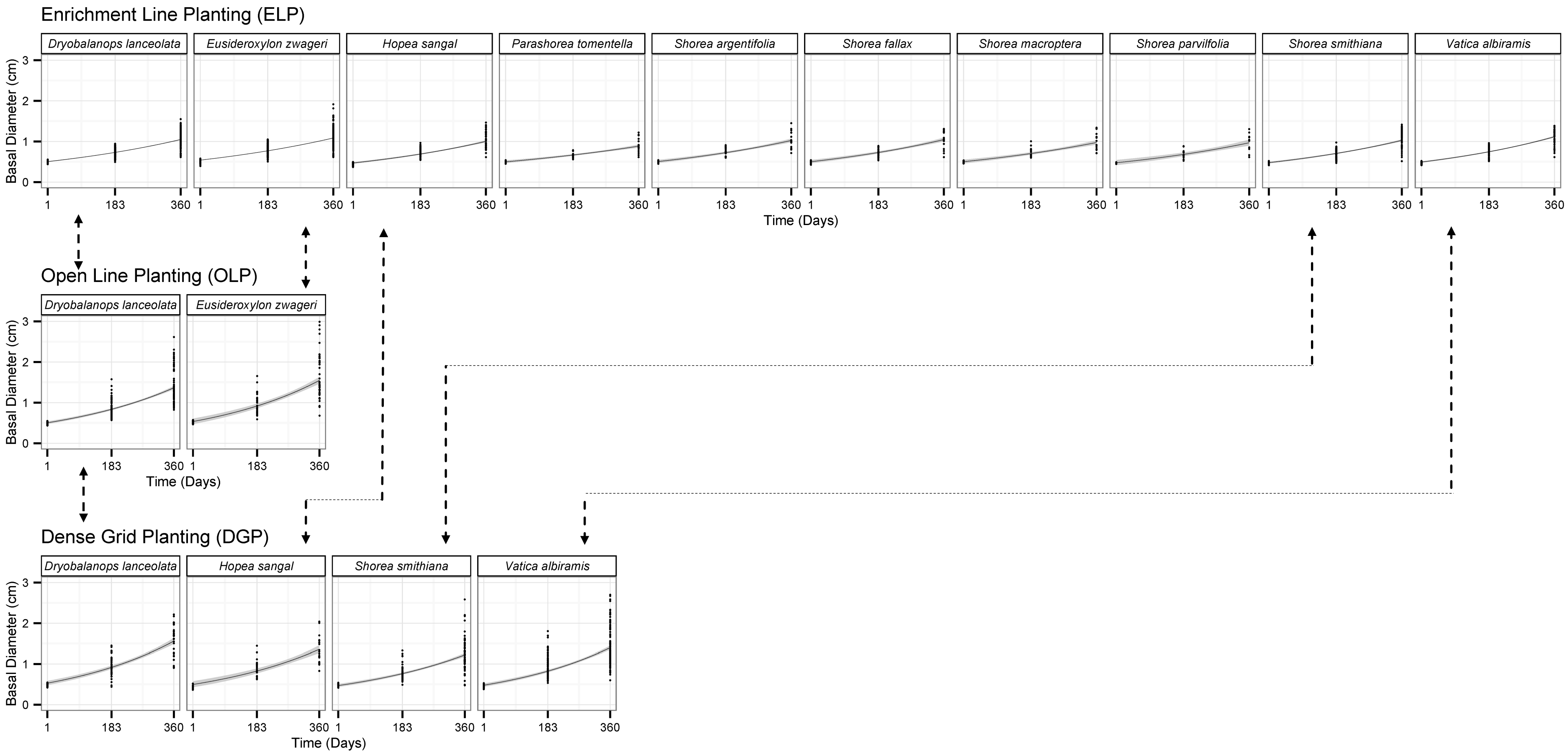


**Figure 3.** Seedling basal diameter through time for each treatment. The lines are regressions for each species in each treatment from GLM analyses with a Gaussian error distribution and natural log link in enrichment line planting treatment ($r^2 = 0.75$), dense grid planting treatment ($r^2 = 0.67$) and open line planting resulting ($r^2 = 0.65$). The grey band indicates the 95% confidence interval.

**Table 3**. The species group performance based on the RGR (cm $cm^{-1}$ $year^{-1}$) by different treatment.

| **Species** | Enrichment line planting (ELP) | Open line planting (OLP) | Dense grid planting (DGP) |
|---|---|---|---|
| *Dryobalanops lanceolata* | 1.05 (1.03 – 1.06) | 1.38 (1.32 – 1.44) | 1.56 (1.47 – 1.66) |
| *Eusideroxylon zwageri* | 1.09 (1.07 – 1.10) | 1.58 (1.50 – 1.67) | 1.36 (1.24 – 1.49) |
| *Hopea sangal* | 1.00 (0.97 – 1.04) | - | 1.22 (1.16 – 1.29) |
| *Parashorea tomentella* | 0.88 (0.83 – 0.95) | - | 1.40 (1.35 – 1.45) |
| *Shorea argentifolia* | 1.02 (0.97 – 1.08) | - | - |
| *Shorea fallax* | 1.05 (0.99 – 1.10) | - | - |
| *Shorea macroptera* | 0.97 (0.92 – 1.04) | - | - |
| *Shorea parvilfolia* | 0.97 (0.89 – 1.05) | - | - |
| *Shorea smithiana* | 1.03 (1.00 – 1.06) | - | - |
| *Vatica albiramis* | 1.12 (1.09 – 1.15) | - | - |

Table 4. The species group probability mortality rates by different treatment.

| **Species** | Enrichment line planting (95% CI) | Open line planting year$^{-1}$ (95% CI) | Dense grid planting year$^{-1}$ (95% CI) |
|---|---|---|---|
| *Dryobalanops lanceolata* | - | 0.02 (0.00 – 0.03) | 0.22 (0.11 – 0.0.36} |
| *Eusideroxylon zwageri* | - | - | - |
| *Hopea sangal* | 0.07(0.02 – 0.16) | - | 0.05 (0.00 – 0.20) |
| *Parashorea tomentella* | - | - | - |
| *Shorea argentifolia* | - | - | - |
| *Shorea fallax* | - | - | - |
| *Shorea macroptera* | - | - | - |
| *Shorea parvilfolia* | - | - | - |
| *Shorea smithiana* | - | - | 0.01 {0.00 – 0.04) |
| *Vatica albiramis* | - | - | 0.06 {0.0.03 – 0.12) |

**Discussion**

In this study, I evaluated the seedling performance of nine Dipterocarpaceae and one Lauraceae species (seedling growth, mortality and survival) in the three different planting treatments: 1) the enrichment line planting on the degraded forest areas, 2) the open line planting on a slope area covered by the non-native grass of *Imperata cylindrica* and 3) the dense grid planting area is located under the girdled *Acacia mangium* trees.

I found seedling growth and mortality were different in the different treatment areas. RGRs differed among species in different treatments and were less variable among species within the same planting treatment. The RGR range was slightly lower in the enrichment line planting treatment than open line planting treatment and dense grid planting treatment. The range of RGR among species in each treatment suggested that there is a relationship between species growth with habitat and planting treatment. However, the lack of the randomized block design limits my comparison. Although the experimental design limits the strength of my conclusions, this study suggest that in the early growth of seedlings, when provided planting medium with adequate nutrient and systematic maintenance, indigenous tree species grow well in full sun lights, with little shading, and even in the area dominated by the invasive *I. cylindrica*. Long-term monitoring will be needed before the association between indigenous species, planting treatment and time is clearly understood. In the future, I recommend a proper experimental design in order to provide estimates of treatment effects that are not confounded by site effects, with planted species well and planting treatments properly replicated and randomized to avoid the potential effects of covarying factors that might confound the treatment effects seen here.

During the early periods of post-planting, the large hole size and the loose planting medium probably assisted the spread of the root system and supporting high growth rates. Maintenance such as grass cutting, weeding, mulching and watering are also very important in order to provide the seedlings with a good environment for growth during the establishment phase. Nussbaum *et al. (*1995) and Vincent & Davies (2003) reported that the application of mulching during early seedling development contributes positively to the rates of growth even in the open and in compacted soil. The high levels and growth and survival in the enrichment line planting and open line planting areas suggest that additional nutrient has potential to support restoration of degraded area.

Comparison of *Dryobalanops lanceolata* – the only species to occur in all three treatment areas - shows that RGR was slightly higher in the dense grid planting treatment area than in the open line planting treatment and enrichment line planting treatment areas. However, higher levels of mortality were observed in *D. lanceolata*, and *Hopea sangal*, *Shorea smithiana* and *Vatica albiramis)* in dense grid planting treatment, although levels were still very low. While my experiment is limited by the lack of a randomized blocked design, the present findings on *D. lanceolata* seem to be consistent with other research by Aiba & Nakashizuka (2007), where they reported that most Dipeterocarpaceae species and specifically *D. lanceolata* can survive at 4% canopy cover in open area. This also accords with observations by Lapongan & Pang (2009), which showed that *D. lanceolata* has the ability to survive in open line planting areas and enrichment line planting. It is interesting to note that all nine species of indigenous dipterocarp of this study can grow well in shaded and open/degraded areas when given sufficient care (water, mulch etc.).

*Eusideroxylon zwageri* was planted in two treatment areas: enrichment line planting and open line planting. In contrast to earlier reports of *E. zwageri* as a slow growing species by Kurokawa *et. al* (2003), I observed *E. zwageri* was amongst the faster growing species in enrichment line planting and open line planting with zero mortality in both treatments. Interestingly *E. zwageri* has a very large seed, and recent work has shown for other species that large seeded species often can have faster growth rates than previously thought (Turnbull *et al.* 2012), but see Paine *et al.* (2015) [add reference]. There are previous studies carried out by Riikka & Lilis (1999) and Kiyono & Hastaniah (2000), where they discovered that *E. zwageri* can grow in degraded areas covered by *Imperata cylindrica*, in logged-over and burned forests in Kalimantan, Indonesia. Furthermore, Kiyono & Hastaniah (2000) found that *E. zwageri* grew slightly better in gaps than closed sites. This supports my early observation on *E. zwageri* performances, which can grow better in open line planting treatment (degraded area covered by *I. cylindrica*) than in enrichment line planting treatment.

Other studies have shown that species from the family Dipterocarpaceae tend to be shade tolerant but the degree of tolerance differs among species (Brown *et al.,* 1999; Takeuchi *et al.,* 2005). Philipson *et al.* (2012) have reported that the basal diameter growth of dipterocarp species varies with habitat and light density. This also accords with my earlier observations, which showed that most species grew slower and were less variable in the shade (under standing trees) with low light penetration in the enrichment line planting treatment, whereas species grew faster but less variable in the open line planting. My results were supported by a study by (Philipson *et al.*, 2014). They found that growth increased with light for all species but that each species had different intrinsic growth rates. This was similarly true for trees growing in the dense grid planting treatment. This finding, while preliminary, suggests that most of planted species in this study have the potential to be used for restoration in open degraded land even where dominated by the non-native grass *Imperata cylindrica* given sufficient care.

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**APPENDIX I**

List of seedling and number of seedling planted by different planting treatment.

| Species | Family | Treatment, plots and number of seedling | | | | | | | No. of seedling |
|---|---|---|---|---|---|---|---|---|---|
| | | Enrichment line planting (ELP) | | | Open line planting (OLP) | Dense grid planting (DGP) | | | |
| | | Plot EPA | Plot EPB | Plot EPC | EOP | Plot DPA | Plot DPB | Plot DPC | |
| *Eurodoxylon zwageri* | Lauraceae | 122 | 125 | 162 | 51 | 7 | 1 | - | 468 |
| *Aquilarla malaccensis* | Thymelaeaceae | - | 1 | 2 | 8 | 1 | - | - | 12 |
| *Dryobalanops lanceolata* | Dipterocarpaceae | 53 | 99 | 95 | 100 | 26 | 15 | - | 388 |
| *Shorea argentifolia* | Dipterocarpaceae | 4 | 8 | 8 | 5 | - | - | - | 25 |
| *Shorea parvifolia* | Dipterocarpaceae | 3 | 5 | 3 | 8 | 1 | - | - | 20 |
| *Vatica albiramis* | Dipterocarpaceae | 1 | 31 | 35 | - | - | 59 | 46 | 172 |
| *Parashorea tomentella* | Dipterocarpaceae | 5 | 13 | 3 | 8 | 1 | 1 | - | 31 |
| *Shorea smithiana* | Dipterocarpaceae | 1 | 41 | 26 | 2 | 4 | 25 | 46 | 145 |
| *Shorea fallax* | Dipterocarpaceae | 4 | 11 | 7 | - | 8 | - | - | 30 |
| *Durio sp* | Bombacaceae | - | 2 | - | - | - | 1 | 7 | 10 |
| *Nephelium lappaceum* | Sapindaceae | - | 1 | 1 | - | - | - | 3 | 5 |
| *Hopea sangal* | Dipterocarpaceae | 11 | 31 | 13 | 1 | 10 | 10 | - | 76 |
| *Anisopetera costata* | Dipterocarpaceae | 1 | - | - | - | 3 | 2 | - | 6 |
| *Shorea macroptera* | Dipterocarpaceae | 1 | 12 | 5 | 2 | - | 1 | - | 21 |
| *Artocarpus odoratissimus* | Moraceae | - | - | 1 | - | - | - | 4 | 5 |
| *Syzygium malaccense* | Myrtaceae | - | - | - | - | 4 | - | - | 4 |
| | | | | | | | | **TOTAL** | **1,418** |

**APPENDIX II**

Description of study sites at different treatment by vegetation cover, topography, soil condition and number of species planted.

| **Treatments** | **Vegetation cover** | **Topography/Drainage** | **Soil condition** | **No. of species analysed (Planted)** |
|---|---|---|---|---|
| Enrichment line planting (ELP) | Mixed secondary forest | Undulating slope/ good drainage | Little humus on topsoil | 10 (24) |
| Open line planting (OLP) | *Imperata cylindrica* | Undulating slope/ good drainage | Clay and bare soil exposed | 2 (10) |
| Dense grid planting (DGP) | *Acacia mangium* | Flat to gentle slope within some steep areas/waterlogged | Thin layer of eluviation and leaves litter | 4 (16) |

**APPENDIX III**

List of the species group cumulative mortality rates by different treatment.

| **Species** | Enrichment line planting mortality (No. of seedlings) | Open line planting mortality (No. of seedlings) | Dense grid planting mortality (No. of seedlings) |
|---|---|---|---|
| *Dryobalanops lanceolata* | 0 (247) | 2 (100) | 9 (41) |
| *Eusideroxylon zwageri* | 0 (409) | 0 (51) | 0 (8) |
| *Hopea sangal* | 4 (54) | 0 (1) | 1 (20) |
| *Parashorea tomentella* | 0 (19) | 0 (8) | 0 (2) |
| *Shorea argentifolia* | 0 (20) | 0 (5) | - |
| *Shorea fallax* | 0 (22) | - | 0 (8) |
| *Shorea macroptera* | 0 (18) | 0 (2) | 0 (1) |
| *Shorea parvilfolia* | 0 (11) | 0 (8) | 0 (1) |
| *Shorea smithiana* | 0 (69) | 0 (2) | 2 (75) |
| *Vatica albiramis* | 0 (67) | - | 7 (105) |

# Chapter 6

## General Discussion

**Introduction**

Tropical forests represent a diverse vegetation type with a mixture of growth forms including trees, lianas, epiphytes, climbers, shrubs and herbs. They are recognized as having the world's highest arboreal species diversity. Previous studies have found that tropical forests also hold a substantial proportion of the carbon stored in terrestrial vegetation (Adachi *et al.,* 2011; Pan *et al.*, 2011; Phillips and Lewis, 2014; Saatchi *et al*., 2011) and that deforestation and forest degradation contributes 10-20% of anthropogenic carbon emissions to the atmosphere (Baccini *et al.*, 2012; Gregory *et al.,* 2010; Phillips and Lewis, 2014).

In general, comparison of unlogged and selectively logged forest reveals marked differences. In selectively logged forest, the altered plant composition in combination with more uniform forest cover (in comparison to primary forest) may lead to different successional processes and rates of regeneration. For native tree species, regeneration rates decrease as disturbance intensity increases and this seems to be related to the density of seeds and seedlings in the seed and seedling bank. Moreover, the success of native species recovery differs depending on the suitability of environment conditions, especially light requirement, which can explain the successional dynamics of specific tree species (Philipson *et al*., 2011).

Both forest vegetation cover dynamics and plant community composition also affect natural seedling growth rates. In many studies, the success of natural recovery by native species is most influenced by local conditions, vegetation composition and structure in the surrounding area, latitude, topographic heterogeneity and seasonality. Furthermore, natural successional processes have been shown to result in losses of soil nutrients and disturbance intensity (Nussbaum *et al.*, 1995). The complexity of interactions within the forest ecosystem means that there are many gaps in ecological knowledge. It is therefore important to understand whether forest altitude has different ecosystem functions, such as carbon storage. Furthermore, it is crucial to determine whether specific indigenous tree species and logging techniques could support forest restoration.

In this thesis, I studied various types of logged and unlogged forest in order to understand key elements of the relationship between tropical forest carbon stocks, dipterocarp trees species diversity and growth. I sampled various tropical forest sites in Sabah, Malaysian Borneo. I give a general introduction to land-use change on Borneo, and a brief introduction to tropical forests and the causes of forest degradation (Chapter 1). I quantify carbon stocks along an elevation gradient in the Crocker Range (Sabah) and shows how carbon stocks decline with increasing elevation between the unlogged forest and selectively logged forest. The chapter presents new empirical data from surveys in 2005 and 2009 in lowland, lower montane, and upper montane forest areas (three sites in unlogged forest and two sites in selectively logged forest). Furthermore, the chapter shows the relationship between elevation and carbon stocks, and found that the lowland logged site is recovering faster and sequestering more carbon than the lower montane site (Chapter 2). Next, I examine aboveground carbon and tree diversity in selectively logged forest, 14 years post-logging. The chapter reported the diversity, density and carbon storage of dipterocarps in different age classes, which were surveyed in nine sites. Carbon stocks are compared with other studies of selectively logged forests in the Malaysian region (Chapter 3). In the next chapter, I examines the effectiveness of rehabilitation planting of dipterocarps by analysing existing data and recent data that I measured in 2014 on dipterocarps growth and survival 21 years after planting in areas logged by either tractor or high lead logging methods. Information on aboveground carbon stocks from other logged and unlogged tropical forest sites are also collated for comparison and as potentially useful sources of information (Chapter 4). I present growth data for 10 species of tree seedlings planted in three different types of degraded landscape (Universiti Malaysia Sabah campus) in order to develop recommendations for forest rehabilitation methods (Chapter 5). Finally, in this chapter (Chapter 6), I elaborate on the main findings of each study. Firstly, the pattern of total aboveground carbon stocks at different altitudes and between types of selectively logged forest. Secondly, I studied the relationship between aboveground carbon stocks and tree diversity after selective logging. Thirdly, I evaluated the performance of dipterocarp species after different logging disturbances. Fourthly, I measured the performance of indigenous species under different planting methods. Finally, I discuss the implications for forest restoration management to enhance the biodiversity and ecosystem functioning of degraded forests.

**Tree Aboveground Carbon Stocks at Different Altitudes**

I found that tree aboveground carbon stocks decreased with increasing altitude (Chapter 2). I demonstrated that lower and upper montane forest store substantial amounts of carbon. Interestingly, undisturbed lower montane forest and upper montane forest ecosystems store higher amounts of carbon than disturbed lowland forest. This may explain how removal of timber in lowland forest has significantly reduced forest ecosystem functioning. The size of sampling plots should be carefully considered when making comparisons to other studies as smaller plots are expected to give a higher variability of carbon stocks (Laumonier *et al.,* 2010; Alves *et al.*, 2010; Kitayama and Aiba, 2002 and Laumonier *et al.*, 2010). They also reported that forest structure, biomass and carbon stocks decreased with increasing of elevation, as was the case with our study.

I also observed higher rates of increase of tree density, tree basal area and tree aboveground carbon in selectively logged forests than in unlogged forest in lowland and lower montane forest. This may support the idea that forest gaps after logging disturbance provide more sun light for sapling growth especially at trees above 5 cm dbh up to 40 cm dbh than forest cover without gap. This finding was similarly observed by (Aiba and Kitayama, 1999) nearby the study area. Unfortunately from an applied perspective, this trend only occurred in lowland forest and not in lower montane forest. It could be that lower montane forest and higher habitats are much more fragile and are less likely to recover naturally. This study suggests both the value of montane forest areas as stores of carbon and their lower capacity for natural recovery indicating the need for conservation of the remaining areas.

**Tree Diversity and Aboveground Carbon Stocks After Selective Logging**

Disturbed forests have low vegetation recovery rates and usually differ according to remnant forest structure and composition. In our study, I found that logged hill dipterocarp forest contains a higher density of trees (1,085 tree $ha^{-1}$) compared to logged lowland dipterocarp forest (874 tree $ha^{-1}$). Although tree density was lower in lowland dipterocarp forest, I found that tree stand basal area and aboveground carbon stocks are still higher than in hill dipterocarp forest suggested a smaller number of larger trees compared to the areas at higher altitude. Lowland dipterocarp forest had a tree stand basal area of 31.23 $m^2$ $ha^{-1}$ and tree aboveground carbon of 110.83 Mg C $ha^{-1}$, in contrast to hill dipterocarp forest which had a lower tree stand basal area of 15.95 $m^2$ $ha^{-1}$ and tree aboveground carbon of 65.14 Mg C $ha^{-1}$.

My study found that after logging, lowland dipterocarp forest decreases in tree density, with Dipterocarpaceae species usually being most affected. However this habitat still plays a more important role in carbon storage in comparison to hill dipterocarp forest. Previous studies also found that selective logging reduces dipterocarp stocks by 55 – 66% (Saner *et al.*, 2012). I found a range of 65.14 – 110.83 Mg C $ha^{-1}$ of aboveground carbon stocks in hill dipterocarp and lowland dipeterocarp forest are within the ranges reported elsewhere in selective logging areas near the Danum Valley Conservation Area, including Sabah Biodiversity Experiment (Pinard and Putz, 1996; Saner *et al.*, 2012; Tangki and Chappell, 2008). This finding suggests that, based on 14 years of recovery, enrichment planting and accompanying silviculture treatments may speed up the rate of recovery of carbon stocks.

**Performance of Dipterocarp Species under Different Logging Disturbance**

Conserving and rehabilitating degraded tropical forest areas demonstrates the possibility of restoring levels of ecosystem functions like carbon storage (Fisher *et al.*, 2011; Koh and Sodhi, 2010; Sodhi *et al.*, 2010). In order to support ecosystem functioning in degraded forests, silviculture treatments and enrichment planting may be used to enhance forest recovery. Based on 21 years of data collection, I found that choosing suitable species for enrichment planting in relation to the logging technique used for previous extraction was crucial for ensuring the success of degraded forest restoration. When comparing four selected species of *Dryobalanops lanceolata, Parashorea* spp.*, Shorea leprosula and Shorea ovalis* I observed differences in growth rate, aboveground carbon stocks and mortality rates in areas logged using high lead versus tractor logging techniques. I found that *D. lanceolata*, *S. leprosula* and *S. ovalis* grew significantly better in the high lead treatment compared to tractor treatment, and *Parashorea* spp., grew better in the tractor treatment compared to the high lead treatment. In the high lead treatment, *Shorea ovalis* was among the fastest growing species with a basal diameter growth rate of 1.11 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.07 – 1.15) and *Dryobalanops lanceolata* was the slowest growing species, with a basal diameter growth rate of 1.08 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.08 – 1.09). In contrast, under the tractor treatment, *Parashorea* spp. was the fastest growing species with a basal diameter growth rate of 1.10 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.07 – 1.14) and *Dryobalanops lanceolata* was the slowest growing species with a basal diameter growth rate of 1.07 cm $cm^{-1}$ $year^{-1}$ (95% CI: 1.07 – 1.08).

In terms of aboveground biomass increment, I found that *Shorea ovalis* had the lowest amounts with 1.04 Mg $ha^{-1}$ (95% CI: 0.91 – 1.19). Under the tractor treatment, *Parashorea* spp. had the greatest tree aboveground carbon stock growth rate with 1.13 Mg $ha^{-1}$ (95% CI: 0.97 – 1.55) and the smallest was *D. lanceolata* with 1.07 Mg $ha^{-1}$ (95% CI: 1.06 – 1.09). The greatest mortality rate was for *S. ovalis* with 0.99 % (95% CI: 0.96 – 1.00) in the high lead treatment and *Parashorea* spp. with 0.96% (95% CI: 0.96 – 1.00) in tractor treatments. *D. lanceolata* had the lowest mortality rate of all species in both the high lead treatment with 0.61 % (95% CI: 0.57 – 0.64) and the tractor treatment with 0.79 % (95% CI: 0.72 – 0.85).

This study finding suggests that it is important to match the tree species functional traits with type of disturbance when selecting species for degraded forest restoration. The performance of enrichment planted seedlings in degraded forest is widely studied in order to understand the limits on the recovery process and other aspects influencing the growth of planted trees. There are many aspects identified as limiting the success of natural regeneration as well as enrichment planting, such as logging disturbance associated with type of logging technique, soil compaction and nutrient availability (Nussbaum *et al.*, 1995), drought (O'Brien *et al.*, 2014), forest gap light levels (Whitmore and Brown, 1996) and light penetration (Bebber *et al.,* 2001; Philipson *et al.*, 2011). Therefore, a comprehensive restoration plan based on the previous history of the area and in-situ environmental conditions may potentially inform the choice of the most appropriate tree species and maintenance system in the future.

**Performance of Indigenous Species under Different Planting Methods**

Suitable tree species and planting methods in the appropriate places are crucial to support the success of forest restoration. Therefore, I examined the performance of ten species of dipterocarp *Dryobalanops lanceolata, Hopea sangal, Parashorea tomentella, Shorea argentifolia, Shorea fallax, Shorea macroptera, Shorea parvifolia, Shorea smithiana, Vatica albiramis* and the Lauraceae *Eusideroxylon zwageri*. I found that *D. lanceolata* grew better under enrichment line planting, open line planting and dense grid planting. The basal diameter growth rate was 1.05 cm $cm^{-1}$ $year^{-1}$ (1.03 – 1.06) in enrichment line planting, 1.38 cm $cm^{-1}$ $year^{-1}$ (1.32 – 1.44) in open line planting and 1.56 cm $cm^{-1}$ $year^{-1}$ (1.47 – 1.66) in dense grid planting. (M. Aiba and Nakashizuka, 2007) and (Lapongan and Kelvin, 2012) also reported that *D. lanceolata* grew better in open areas even in line planting and enrichment line planting.

I observed that there was no mortality of *D. lanceolata* in enrichment line planting, 20% in the dense planting treatment and 2% in the open line planting treatment. *E. zwageri* had excellent early performance with a growth rate of 1.58 cm $cm^{-1}$ $year^{-1}$ (1.50 – 1.67) in open line planting and a growth rate of 1.09 cm $cm^{-1}$ $year^{-1}$ (1.07 – 1.10) in enrichment line planting. This is in contrast to a study conducted by (Lapongan and Kelvin, 2012), which found that after 10 years of planting all *E. zwageri* had died. It also found zero mortality rates in both enrichment line planting treatment and open line planting treatment.

In this study, I found that *V. albiramis* grew best in the enrichment line planting treatment, while *E. zwageri* grew best in the open line planting treatment and *D. lanceolata* grew best in dense grid planting. I suggest that with a suitable planting medium, adequate nutrients and systematic maintenance, indigenous tree species may grow well in full sunlight, and even in areas dominated by the invasive *Imperata cylindrica*. However, this restoration scheme did not use a randomised design and the results should be considered preliminary with this caveat until they have been repeated in randomised studies or confirmed by meta-analysis of studies from multiple sites.

**Implications for forest management**

Rapid deforestation and the increasingly large areas of degraded lands in tropical regions have increased the need for interventions to restore biodiversity and enhance ecosystem functioning. Deforestation through logging and land conversion for agricultural expansion has damaged ecological services, and driven loss of biodiversity and many timber and non-timber forest products. In recent years, many tropical forest studies have shown that the restoration of degraded forest enhances biodiversity. As well as conserving and protecting unlogged forest, enrichment planting of degraded forest may restore biodiversity. Many studies have found that degraded forests vary in forest cover and biodiversity, which is dependent on disturbance intensity. This influences natural regeneration, which may be rapid in disturbed areas where some residual trees, seedlings and soil nutrients are still present in the landscape.

Our study indicates that tropical forests at different altitudes have differing biophysical characteristics and ranges of stored carbon (Chapter 2). This is likely to have been influenced by soil characteristics, temperature, rainfall and slope angle (Spracklen and Righelato, 2014). Logging changes the ecosystem functioning along the altitudinal gradient. To avoid impacts on the ecosystem and difficulty in restoring the lower montane forest, forest managers and decision makers should understand the complexity of the vegetation community in the area undergoing disturbance. The concept of sustainable and systematic management should not be compromised and such areas may potentially be conserved to enhance ecosystem functioning.

Tree density and carbon stocks appear to differ between logged lowland and hill dipterocarp forest (Chapter 3). In terms of carbon storage, selectively logged hill dipterocarp forest contained lower carbon in contrast to selectively logged lowland dipterocarp forest. This may suggest that harvesting plans should consider forest altitude, where hill dipterocarp forests only have about 48% of carbon stocks compared to lowland dipterocarp forest. The different carbon stocks between selectively logged lowland and hill dipterocarp forest may be an effect of different logging intensities (Pinard and Cropper, 2000; Putz *et al.,* 2008b; Sist *et al*., 1998b), where lowland dipterocarp forest still has remnant large trees. In the case where timber extraction was similar between forest types, this might indicate that hill dipterocarp forest was heavily damaged due to muddy, wet terrain, which made harvest and extraction of timber difficult. In relation to reduced-impact logging, muddy, wet terrain should be avoided to prevent more damage to the forest stand during harvesting and timber extraction (Putz *et al.,* 2008a; Sist *et al*., 1998a).

In another study, I also found that forest restoration plays an important role in enhancing degraded forest functioning, especially with regard to carbon storage. Different species of dipterocarp have different responses to the type of logging (Chapter 4). This suggests that restoration project managers should understand the site history in addition to the local environmental conditions. For example, tractor-logging techniques cause soil compaction but does not do much damage to the plants and other communities surrounding the felling area and skid tracks. More damage will occur when a high density of trees is taken in a small area. Therefore, the logging system is important to reduce damage and support forest recovery (Priyadi, 2003). Restoration through enrichment planting and indigenous species selection also may potentially support forest recovery and ecosystem functioning (Karam *et al.*, 2012). Therefore, choosing the right dipterocarp species and planting methods for a particular location may potentially support the successful achievement of forest restoration goals (Ådjers *et al.*, 1995; Azani *et al.*, 2011).

This highlights that enrichment planting serves only specific objectives. For example, enrichment planting may improve tree species richness in very low quality forests with fewer tree species, especially the Dipterocarpaceae species (Kettle, 2009). As a commercial timber, Dipterocarpaceae species are usually felled during logging, which means that in some cases the species will be totally removed and go locally extinct. Dipterocarpaceae tree species are very locally specific and rarely recover without a sufficient seed source. I suggest that enrichment planting is a necessity in tropical forest management, especially when the quality of residual forest stands is poor. Where there is a lack of trees and where the removal of commercial trees occurred, enrichment planting is a good option to restore selectively logged forest (Lamprecht, 1989). In addition, implementing enrichment planting to increase tree diversity may be appropriate to support biodiversity conservation (Hector *et al.,* 2011).

Furthermore, with regard to basal area and tree aboveground carbon, the results of the enrichment planting in this study represent the planted trees in selectively logged forest. These findings help us to understand why selectively logged forest with enrichment planting has a higher total basal area and tree aboveground carbon compared to selectively logged forest without enrichment planting.

Early observation of restoration techniques in urban degraded forest using indigenous species also provides an opportunity to support urban forest restoration (Chapter 5). In this study, I demonstrated that degraded areas covered by *Acacia mangium* and *Imperata cylindrica* may be restored using indigenous species. Specific attention was paid to supporting growth performance, such as preparing the planting media during planting and frequent weeding maintenance. I found that indigenous species growth was substantial and differed depending on planting methods applied.

**Future research**

*Comparison between unlogged forest and selectively logged forest*

The outcome of this study has filled several general knowledge gaps in our understanding of forest structure and carbon stocks of unlogged forest and selectively logged areas of lowland and hill dipterocarp forest along an altitudinal gradient from around 600 to 1800 m above sea level. Logged forest usually has low quality structure, which is related to low tree density and may consist of lower species diversity. As in other studies, the comparison between unlogged and selectively logged forest shows that logged forests have a lower density of trees, reduced carbon stocks and low tree species diversity.

Future research to understand the changes of forest structure at different altitudes would be interesting in order to identify key factors that cause changes in forest types. It would also be interesting to know how the success of regeneration varies along the altitudinal gradient from lowland to upper montane forest. Increased sampling between study experiments would be useful in order to develop better estimates and provide more accurate results relating to forest structure and carbon stocks, which are important for long term monitoring. Given the sampling design of this study, the estimate of carbon stocks presented here might not be comparable to other studies due to the different sizes of the plots. However, the carbon stock estimation carried out here makes it possible to improve our ability to manage the unlogged and selectively logged forest areas at different altitudes.

*Effectiveness of enrichment planting*

The results of restoration through enrichment planting in this study have highlighted several knowledge gaps after 21 years of experimental replanting. The current study found that the densities of some species of seedlings planted were very low after 21 years. I found very high mortality occurred in some species and this was discussed in Chapter 4.

The question of how effective enrichment is in restoring degraded forest has arisen due to the low survival of selected species after 21 years of planting and given its relatively high cost. Future research is required in order to understand the ability of enrichment planted seedlings to compete with the naturally existing seedlings, climbers and other pioneer species.

**Conclusion**

These studies provide empirical information to fill knowledge gaps on managing tropical forest landscapes. I surveyed tropical forests with different management histories to understand species diversity and carbon stocks before and after logging at different altitudes, and performance of planted indigenous species at various levels of degradation due to different logging techniques and planting methods. Our study found that 1) logging at higher altitude would cause more damage to forest structure and decrease forest ecosystem functioning in these sensitive areas; 2) planting indigenous species in restoration projects may potentially support the recovery of degraded forest including in urban areas; and 3) maintenance of planted seedlings as well as the planting area may contribute to the success of restoration projects.

In order to support biodiversity conservation, I suggest that 1) remaining higher altitude forest must be conserved and disturbed areas should be restored; 2) logging activities must be planned carefully to reduce damage to forest composition; 3) degraded forest restoration should consider suitable indigenous species and appropriate planting methods. However, only with long-term, continuous monitoring will comprehensive empirical information on the effect of landscape changes on tropical forest structure, biodiversity and ecosystem functioning be provided. Meanwhile, restoration of degraded forest could potentially support forest recovery, which may enhance the management of altered forest ecosystems.

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# Curriculum Vitae

**Personal Information**

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| **Education** | **Year** |
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| PhD in Ecology,<br>"Dynamics of forest structure, tree aboveground carbon and Dipterocarpaceae seedlings growth in selectively logged forest of Sabah, Malaysian Borneo."<br>*University of Zurich, Switzerland.* | 2011 - Present |
| M.Sc. Forestry (Geographic Information System in Forestry),<br>"Development of RISDA Smallholders´ Database in Tanah Merah/Machang Districts, Kelantan."<br>*Faculty of Forestry, Universiti Putra Malaysia (UPM), Malaysia.* | 2007 |
| Bac. of Forestry Science<br>"Potential of Nature Tourism in Tanjung Tuan, Bird Sanctuary, Malacca."<br>*Faculty of Forestry, Universiti Putra Malaysia (UPM), Malaysia.* | 1999 |

**Professional Experience**

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| 2008 – Present | Lecturer, Institute for Tropical Bilogy and Conservation, Universiti Malaysia Sabah (UMS), Malaysia. |
| 2006 - 2008 | Lecturer, Asian Tourism Institute (Asian Tourism International College), Sabah, Malaysia. |
| 2004 - 2006 | Forest Officer (GIS/Technical Support), Forestry, Processing & Marketing Division (Yayasan Sabah Group), Sabah, Malaysia |
| 2001 - 2003 | Agriculture (Horticulture) Officer- G41, Park and Lanscaping Department, Putrajaya Corporation, Putrajaya, Malaysia |
| 2000 - 2001 | Research Assistant (GIS/Remote Sensing), Faculty of Engineering, Universiti Putra Malaysia (UPM), Malaysia. |

**Awards/ Achievement**

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| 2011 | Best Service Certificate **2010** University Universiti Malaysia Sabah (UMS), |

**Research Seminars and Conferences**

| | | |
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| 1. | International Conference on HEART OF BORNEO +5 and Beyond "Shaping and Nurturing Sabah's Future Together" | 6 – 7 Nov 2012 (Participant)<br>**Venue:** The Magellan Sutera, Sutera Harbour Resort, Kota Kinabalu, Sabah, Malaysia. |
| 2. | Regional Conference on Protected Area and Biodiversity Management in Southeast Asia<br><br>**Poster title**: Forest structure dynamics in lowland and hill dipterocarp logged-over forest in Sabah (North Borneo), Malaysia. | 24 – 25 June 2014 (Poster presenter)<br>**Venue:** The Magellan Sutera, Sutera Harbour Resort, Kota Kinabalu, Sabah, Malaysia. |
| 3. | PhD Program in Ecology Apéro, IEU, UZH<br><br>**Poster title**: Comparison of forest restoration following different selective logging techniques in Sabah, Malaysian Borneo | 20 Nov 2014<br>(Poster presenter)<br>**Venue:** IEU, UZH |

**Additional Relevant Competences**

| | | |
|---|---|---|
| **Languages** | : | – Malay (native), English (fluent), German (intermediate writing, basic speaking), Indonesia (fluent), Japanese (basic speaking), Mandarin (basic speaking), Sabah Natives Dusun/Kadazan |
| **Analysis** | : | – Linear and generalized linear models (good)<br>– Mixed-effect models (good)<br>– Multivariate analysis (basics)<br>– Satellite images analysis (Landsat, SPOT & IKONOS)<br>– Geographic Information System (GIS) and Spatial analysis |
| **Fieldwork** | : | – Forest survey & mapping – GIS & Remote Sensing<br>– Forest Inventory (permanent plot, tree identification, forest profile)<br>– Herbarium –(specimen collection and preservation) |
| **Programs used** | : | – Office: Word, Excel, Power Point, Keynote<br>– Statistics: R Statistic, SPSS<br>– Mapping: ArcGIS, ArcMap, ArcView, ArcInfo<br>– Satellite imagery: Erdas Imagine |
| **Driver's license** | : | – Obtained in 1993 |